CHAPTER 5

INDUSTRY SUBCATEGORIZATION FOR EFFLUENT LIMITATIONS GUIDELINES AND STANDARDS

5.0 INTRODUCTION

The Clean Water Act requires EPA to consider a number of different factors when developing Effluent Limitations Guidelines and Standards (ELGs) for a particular industry category. These factors include the cost of achieving the effluent reduction, the age of the equipment and facilities, the processes employed, engineering aspects of the control technology, potential process changes, nonwater quality environmental impacts (including energy requirements), and factors the Administrator deems appropriate. One way EPA takes these factors into account is by breaking down categories of industries into separate classes of similar characteristics. The division of a point source category into groups called "subcategories" provides a mechanism for addressing variations among products, raw materials, processes, and other parameters that result in distinctly different effluent characteristics. Regulation of a category by subcategory ensures that each subcategory has a uniform set of effluent limitations that take into account technology achievability and economic impacts unique to that subcategory.

The factors that EPA considered in the subcategorization of the CAFO point source category include:

- Animal production processes
- Waste management and handling practices
- Wastes and wastewater characteristics
- Waste use practices
- Age of equipment and facilities
- Facility size
- Facility location

EPA evaluated these factors and determined that subcategorization of this point source category is necessary. Based on these evaluations, the CAFO point source category has been divided into four subcategories for the purpose of issuing effluent limitations. These four subcategories are:

- Subcategory A (Subpart A): Horses and sheep

- Subcategory B (Subpart B): Ducks
- Subcategory C (Subpart C): Dairy and beef cattle other than veal calves
- Subcategory D (Subpart D): Swine, poultry, and veal calves

Section 5.1 briefly discusses the background of the subcategorization of the CAFO point source category including the 1974 Feedlots ELG. Section 5.2 discusses the subcategorization basis of the CAFO industry.

5.1 Background

Under the 1974 rulemaking, EPA divided the point source category into two subcategories: (1) Subpart A - all subcategories except ducks, and (2) Subpart B - ducks on dry lots and wet lots. Subcategories addressed under Subpart A include

- Beef cattle, open lot
- Beef cattle, housed lot
- Dairy cattle, stall barn with milk room
- Dairy cattle, free stall barn with milking center
- Dairy cattle, cowyard with milking center
- Swine, open dirt or pasture lots
- Swine, housed with slotted floor
- Swine, open or housed with solid concrete floor
- Chickens, broilers housed
- Chickens, layers (egg production) housed
- Chickens, layer breeding and replacement stock housed
- Turkeys, open lot
- Turkeys, housed lot
- Sheep, open lot
- Sheep, housed lot
- Horses, stables

This subcategorization was developed primarily on the basis of animal type and production processes employed. Secondary criteria were product produced, prevalence of the production process employed, and characteristics of waste produced.

On January 21, 2001 (66 FR 2960), EPA published a proposal to revise and update the ELG for feedlots (beef, dairy, swine, and poultry operations) that included two new subcategories:

- Subpart C: Dairy and beef cattle, other than veal calves, including heifer operations.
- Subpart D: Swine, poultry, and veal calves.

This subcategorization scheme explicitly addressed immature cattle and swine weighing less than 55 pounds, which were not explicitly included in the previous subcategorization scheme, and established new subcategories for swine, poultry, and cattle operations (separate from horses and sheep). The proposal did not affect Subpart B, and retained Subpart A for horses and sheep.

5.2 <u>Subcategorization Basis for the Final Rule</u>

The CAFO industry has changed operational practices considerably in the past few decades since promulgation of the 1974 ELG. During the development of this revised ELG, EPA determined that the basis for subcategorization needed to reflect current industry trends. In developing the final CAFO rule, EPA used information from USDA, industry, EPA site visits, data from EPA enforcement and inspection efforts, and public comments to evaluate each of the statutory factors listed above in Section 5.0 as they affect the current industry. EPA also considered maintaining the basis of subcategorization used in the 1974 ELG and refining the performance expectations for these facilities. Based on these analyses, EPA retained the subcategorization scheme proposed on January 21, 2001. The subcategories are

- Subpart A: Horses and sheep.
- Subpart B: Ducks.
- Subpart C: Dairy and beef cattle, other than veal calves, including heifer operations.
- Subpart D: Swine, poultry, and veal calves.

The remainder of this section discusses the factors considered for the subcategorization of the CAFO industry and those that were selected as the basis of the final subcategories.

5.2.1 Animal Production, Manure Management, and Waste Handling Processes

Production processes in the CAFO industry include all aspects of animal husbandry, animal housing, and type of animal operation. The type of production process, including animal type and housing, was one of the primary levels of subcategorizing the industry in the 1974 ELG. Furthermore, the waste handling and manure management practices at CAFOs are closely tied to housing practices and support the rationale for using these processes as a basis for subcategorization. As discussed in Chapter 4, Large beef feedlots, dairies, and heifer operations typically have outdoor confinement lots where animals are housed for all or at least a portion of their time. Large beef, dairy, and heifer operations keep animals in confinement on outdoor lots and generate and manage both solid manure and liquid process wastewater that are affected by climate, especially precipitation.

More specifically, the majority of Large beef feedlots are open feedlots, which are usually unpaved. These types of operations may use mounds in the pens to improve drainage and provide areas that dry quickly, because dry resting areas improve cattle comfort, health, and feed utilization, all of which contribute to efficient animal weight gain. In open feedlots, protection from the weather is often limited to a windbreak near the fence in the winter and sunshade in the summer; however, treatment facilities and hospital areas for the cattle are usually covered. Animals are fed two or three times daily, so a concrete apron is typically located along feedbunks and around waterers (i.e., heavy traffic areas). Wastes produced from beef feedlots include manure, bedding, spilled feed, and contaminated runoff. Unroofed confinement areas typically have a system for collecting and confining contaminated runoff. The runoff is typically managed in a storage pond and the manure from the open lots is often scraped and stacked into mounds or stockpiles. Beef feedlots typically use a settling basin to remove bulk solids from the liquid waste stream, reducing the volume of solids before the stream enters a storage pond.

The primary function of a dairy is the production of milk, which requires a herd of mature dairy cows that are lactating. In order to produce milk, the cows must be bred and give birth. Therefore, a dairy operation may have several types of animal groups present including calves, heifers, cows that are close to calving, lactating dairy cows, dry cows, and bulls. Animals at dairy operations may be confined in a combination of freestall barns, outdoor dry lots, tie stalls, or loose housing (barns, shades, and corrals). Some animals may be allowed access to exercise yards or open pastures. At dairies, the most common type of housing for lactating cows includes freestalls, dry lots, tie stalls/stanchions, pastures, and combinations of these. Freestalls are the housing systems used by practically all Large dairy operations. The cows are not restrained in the freestalls and are allowed to roam on concrete alleys to the feeding and watering areas. Manure collects in the travel alleys and is typically removed with a tractor or mechanical alley-scraper, by flushing with water, or through slotted openings in the floor (refer to Section 4.3.5 for a more detailed description of waste handling). Dry lots are outside pens that allow the animals some exercise, but do not generally allow them to graze. These milking cows are not likely to spend their entire time in a freestall or on a dry lot, as they need to be milked at least twice a day at a tiestall or in a milking parlor.

Most dairies have both wet and dry waste management systems. The dry waste (manure, bedding, and spilled feed) is typically collected from the housing and exercise areas by tractor scrapers and stored where an appreciable amount of rainfall or runoff does not come in contact with the waste. The wet waste (water from the barn and milking parlor cleaning operations, manure, and contaminated runoff) is typically stored in anaerobic lagoons. Like beef feedlots, dairies tend to use solid separators to remove bulk solids from a liquid waste stream. Waste associated with dairy production includes manure, contaminated runoff, milking parlor waste, bedding, spilled feed, and cooling water. Lactating cows require milking at least twice a day and are either milked in their tie stalls or are led into a separate milking parlor. The milking parlor is typically cleaned several times each day to remove manure and dirt via flushing or hosing and scraping.

Stand-alone, heifer-raising operations provide replacement heifer services to dairies. These heifer operations often contract with dairies to raise heifers for a specified period of time. Heifer-raising operations use two primary methods for raising their animals. One is to raise the cattle on pasture and the second is to raise heifers in confinement. These confined heifer operations tend to raise heifers in the same way that beef feedlots raise their cattle. The heifers are typically housed on unpaved open dry lots. Wastes produced from heifer operations include manure, bedding, and contaminated runoff. Unroofed confinement areas typically have a system for collecting and confining contaminated runoff. The runoff is typically managed in a storage pond and the manure from the open lots is often scraped and stacked into mounds or stockpiles. Heifer operations may also use a settling basin to remove bulk solids from the liquid waste stream.

In all cases, these open lots and outdoor pens expose large surface areas to precipitation, generating large volumes of storm water runoff contaminated with manure, bedding, feed, silage, antibiotics, and other process contaminants. Based on the similarity of the production, housing, and waste management processes for beef feedlots, dairies, and heifer operations, EPA developed a new subcategory, Subpart C, to address these operations under the revised ELG. EPA believes that these operations use similar technologies (e.g., storm water diversion, solid separation) to reduce effluent discharges from production areas given that all of these operations must manage storm water runoff from open lots as well as the storm water that contacts food or silage.

In contrast, nearly all Large swine, poultry, and veal calf operations use total confinement housing. These confinement buildings prevent contact of runoff and precipitation with the animals and manure. Furthermore, these operations are able to manage manure in a relatively dry form, or contain liquid wastes in storage structures such as lagoons, tanks, or under-house pits that are not greatly affected by precipitation. Operations using confinement housing differ most notably from operations using outdoor open lots in that they are constructed, or can be relatively easily configured, in a manner that prevents the generation of large volumes of contaminated storm water runoff. Thus they do not need to manage large, episodic volumes of storm water runoff. At most, operations using total confinement housing need only to manage the precipitation falling directly into manure-handling and storage structures (e.g., lagoon or open tank).

For example, swine operations may be categorized by six facility types based on the life stage of the animal in which they specialize: farrow-to-wean, farrow-nursery, nursery, grow-finish, farrow-to-finish, and wean-to-finish. Many operations have the traditional full range of pork production phases in one facility, known as farrow-to-finish operations. Most nursery and farrowing operations, as well as practically all large operations of any type, raise pigs in pens or stalls in environmentally controlled confinement housing. These houses commonly use slatted floors to separate manure and wastes from the animal. Swine waste includes manure, spilled feed, and water used to clean the housing area or dilute the manure for pumping. Most confinement hog operations use one of three waste handling systems: flush under slats, pit recharge, or deep under-house pits. The flushed manure and manure from pit recharge systems is typically stored in anaerobic lagoons or tanks while deep pit systems store manure under the confinement houses.

Based on the information in Chapter 4 as well as other information in the record, EPA is including operations with immature swine as CAFOs under Subpart D based on their production and waste-handling practices. Immature swine operations were not specifically addressed in the 1974 ELG because immature animals were typically raised at a farrow-to-finish operation and not at a separate operation like today. Although many large operations continue to have the full range of production phases at one facility, these are no longer the norm. Waste from immature operations is often flushed and managed in a lagoon or pit, just like operations that manage mature pigs. Due to the increased construction and reliance on immature swine operations, EPA maintains that these operations should be specifically addressed to ensure protection of surface water quality. Because the immature operations use virtually the same animal production and waste management processes and are expected to use similar effluent reduction practices and technologies as mature swine operations, EPA has included these immature operations under Subpart D.

Poultry operations can be classified into three individual sectors based on the type of commodity in which they specialize. These sectors include operations that breed or raise broilers, or young meat chickens, turkeys and turkey hens; and hens that lay shell eggs (layers). There are two types of basic poultry confinement facilities—those that are used to raise turkeys and broilers for meat, and those that are used to house layers. Both types use total confinement houses. Broilers and young turkeys are grown on floors on beds of litter shavings, sawdust, or peanut hulls, while layers are confined to cages suspended over a bottom story in a high-rise house, or over a pit, or a belt or scrape gutter. The majority of egg-laying operations use dry manure handling but some use liquid systems that flush waste to a lagoon. Poultry waste includes manure, poultry mortalities, litter, spilled water and feed, egg wash water, and also flush water at operations with liquid manure systems. Manure from broiler, breeder, some pullet operations, and turkey operations is allowed to accumulate on the floor where it is mixed with the litter. In the chicken houses, litter close to drinking water access forms a cake that is removed between flocks. The rest of the litter pack generally has low moisture content and is removed every 6 months to 2 years, or between flocks. The removed litter is stored in temporary field stacks, in covered piles, or in stacks within a roofed facility to help keep it dry.

Veal calf operations raise male dairy calves for slaughter. Veal calf are raised almost exclusively in confinement housing, generally using individual stalls or pens. Floors are constructed of either wood slats or plastic-coated expanded metal, while the fronts and sides are typically wood slats. The slotted floors allow for efficient removal of waste. Veal calves are raised on a liquid diet and their manure is highly liquid. Veal calf waste consists of manure, flushing water, and spilled liquid feed. Manure is typically removed from housing facilities by scraping or flushing from collection channels and then flushing or pumping into liquid waste storage structures, ponds, or lagoons. Veal calf manure is typically handled in a liquid waste management system like that used in swine operations and not like the outdoor stockpiled manure at beef feedlots. Veal calf operations maintain their animals in total confinement housing like swine and poultry operations as opposed to the outdoor lots used at most beef feedlots and dairies.

Nearly all Large swine, veal calves, and poultry operations confine their animals under roof, avoiding the use of open animal confinement areas that generate large volumes of contaminated storm water runoff. These operations differ most notably from beef and dairy operations in that they, in most cases, do not have to manage the large volumes of storm water runoff that must be collected at beef and dairy operations. While swine, veal calves, and certain poultry operations that manage wastes in uncovered lagoons must be able to accommodate precipitation, they are largely able to divert uncontaminated storm water away from the lagoons and minimize the volume of wastes they must manage. Furthermore, swine, poultry, and veal calf operations use similar technologies (e.g., reduction of fresh water use, storage of manure in covered or indoor facilities, recycle of flush water) to reduce effluent discharges.

Another basis for subcategorization is the type of production system in place. In the case of CAFOs that means the type of animal operation. For example, EPA considered whether the swine production pyramid of breeding, nursery, and finishing should be used as a basis of subcategorizing swine CAFOs, or whether subcategorization should be based on specific animal breeds, animal weights, type of feed, or other process-specific factors. In evaluating the information in the record, EPA determined there were too many life-cycle variables to allow reasonable subcategorization based on the type of production system, and that segmentation based on these variables was unlikely to result in substantially different effluent characteristics or effluent limitations for each subcategory. For example, such an approach as applied to chickens would result in over a dozen subcategorizations with considerable overlap. Yet the amount of litter and manure nutrients generated in 1 year by six flocks of broilers raised for 49 days each is not significantly different from that generated by seven flocks raised for 42 days (see Chapter 6 for additional information). Furthermore, such an operation could be subject to varying standards at different times of the year. EPA determined segmentation in this fashion would complicate rather than simplify the regulation.

5.2.2 Other factors

EPA analyzed data from USDA, universities, industries, and the literature on manure and waste characteristics for AFOs. Site-specific factors such as animal management, feeding regimens, and manure handling will affect the form and quantity of the final manure and waste products to some degree. However, for a given animal type, there is reasonably consistent manure generation, and similar pollutant generation. See Chapter 6 for more information. EPA considered, but rejected, basing subcategorization on the pollutant content of the wastes, in particular because this would not provide more effective control of CAFO discharges.

During the rulemaking, EPA evaluated subcategorization based on waste characteristics — one based on an expected nutrient content (e.g., P) of the manure or the mass of a particular nutrient. Although EPA believes that setting thresholds based on nutrient content of the manure may encourage the development of reduction strategies, it would not adequately reflect the form of the nutrient present in the manure (i.e., organic or inorganic, soluble fraction). Similarly, using the mass of the nutrient as the basis for subcategorization could possibly encourage manure management and nutrient conservation. See Chapter 2 for a discussion on the merits of P production as a metric for establishing regulatory thresholds. EPA believes using this same approach for subcategorization creates difficulties. For example, such an approach would significantly increase the complexity of identifying CAFOs (e.g., a facility is a CAFO if it produces "x" pounds of P) and cost of implementing the ELG (by requiring rigorous sampling, additional recordkeeping, and more frequent reporting). Furthermore, while some practices can be used to affect manure generation and nutrient outputs, others are only effective for select animal species (such as adding phytase to feed), or may provide limited benefit to overall manure management at the operation (for example, smaller feed pellets increase digestibility and may decrease nutrient excretion in the manure but will also decrease solid-liquid separation efficiency). The nutrient mass excreted can also change based on feeding strategies, feed supplements, and the amount of time elapsed before sampling. See Chapter 8 for more information. These factors make it harder for the CAFO to manage, and difficult for the permitting authorities to implement the regulation. Therefore, EPA rejected both of these approaches due to their limitations, increased costs, and complexity.

EPA considered basing subcategorization on water use practices such as dairy, swine, and layer operations that employ technologies such as flush waste handling systems, deep pits, and scrapers. In considering these practices as a basis for subcategorization, EPA evaluated the cost for these sectors to comply with the various technology options, and concluded that water use practices did not prevent a facility from achieving the performance standards. (However, some technologies and practices for water use/reuse/recycle can be used to substantially reduce costs of certain technology options. See Chapter 8 and the Cost Report for more information.) EPA also determined that a subcategorization scheme based on water use practices could, in some cases, provide a disincentive for a facility to reduce fresh water consumption. Therefore, EPA did not select water use practices as a basis for subcategorization.

EPA evaluated the age of facilities as a possible means of subcategorization because older facilities may have different processes and equipment that could require the need for different or more costly control technologies to comply with regulations. EPA conducted site visits and consulted with EPA regions, enforcement officials, land grant and extension experts, and industry to collect information about AFOs and waste management practices. Specifically, EPA visited more than 115 beef feedlots; dairies; and swine, poultry, and veal calf operations throughout the United States. EPA visited a wide range of operations; including those demonstrating new and innovative technologies as well as old and new facilities were visited. EPA's analyses and site visits indicate that older facilities are similar to new facilities in a number of ways. Through retrofitting, expansions, and desire to maximize animal production, many older facilities have implemented technologies and practices used by the newer facilities in order to remain competitive. Even though confinement housing may have a 20- to 30-year useful life, modifications are continuously made to the internal housing structures at CAFOs such as replacement of floor materials, installation of new feeding systems, and improvements to drinking water equipment. These improvements and modifications are even more apparent at operations that have expanded the size of the facility. For example, many wet layer operations are retrofitting to dry manure systems, few, if any, Large swine facilities use open lots, and beef feedlots are diverting clean storm water away from the feedlot and manure storage areas. These and other examples of modifications are documented in the record (See W-00-27, Section 5.3). EPA determined that the age of the facility does not have an appreciable impact on the wastewater characteristics, especially the total amount of nutrients to be managed, and was not considered as a basis for subcategorization.

EPA also considered subcategorization on the basis of facility size and analyzed several size groups for each major livestock sector. Within each size group, EPA considered the predominant practices, and developed cost models to reflect these baseline practices. EPA found that all Large CAFOs used similar practices, though the smaller the operation, the more diverse the range of practices employed. EPA also determined that farm size did not consistently influence the ability of the operation to achieve the desired performance standards for each technology option. Additionally, EPA did not find that CAFO size consistently influenced the ability of the facilities to achieve the performance standards for each technology option (see the Economic Analysis document for more information on impacts). Finally, pollution potential from all AFOs within a broad size range is approximately the same per unit of animal production for all sizes of facilities. Therefore, to minimize confusion, potential inconsistencies, and administrative burden, EPA determined that the ELG applies to anyone defined as a Large CAFO and did not select to subcategorize further on the basis of facility size.

With respect to geographic location, EPA analyzed key production regions for each major livestock sector and considered the predominant practices within each of these regions. Next EPA identified different treatment, storage, and handling practices based on geographic location, and developed cost models to reflect these baseline practices. EPA acknowledges that geographic considerations, especially temperature and rainfall, may affect manure storage and handling, yet the practices employed by the industry do not vary considerably within a region. For example, while pits or lagoons may be used with different frequencies in any given region, these two technologies are used all over the country. EPA could not draw clear distinctions for each locale that would form a basis for subcategorization. Furthermore, EPA's cost analysis shows location does not prevent an operation from meeting the performance standards. See the Cost Report for more information. Therefore, there is no need to develop subcategorization by location. This is further supported by reported compliance rates by each EPA region; compliance did not vary by region. Therefore, EPA concludes subcategorization by location is difficult to implement, largely impractical, and, even if selected, would not provide for additional control of discharges.

EPA also evaluated pollution-control technologies currently being used by the industry as a basis for establishing regulations. The treatability of waste was not a factor for categorization since wastes from CAFOs are concentrated and present in such quantities that no direct discharge from the production area is currently allowed. Pollution-control technologies are often complementary to or directly part of the production or manure management process, therefore the rationale for using such processes as a basis for subcategorization is further supported by the potential use of pollution-control technologies as a basis for subcategorization. However, EPA believes that the use of pollution-control technologies only to segment the industry may result in disincentives for new and innovative treatment technologies, especially the transfer of technologies between animal sectors (for example, the recent application of high-rise housing to swine operations, a technology well established by layer hen operations). Although the current use of pollution-control technologies did assist EPA in identifying the best management practices addressed in the final ELG, EPA did not believe pollution-control technologies would serve as a better basis for subcategorization than the production of manure management processes.

Finally, EPA evaluated whether Nonwater Quality Impacts (NWQIs) could form a basis for subcategorization. NWQIs include changes in air emission and energy use at CAFOs such as those resulting from transportation of manure and wastes to off-site locations, and emissions of volatile organic compounds to the air. See the NWQI report for additional information. While NWQIs are of concern to EPA, the impacts are the result of individual facility practices and do not apply uniformly to different industry segments. To the extent there are similarities, these similarities do not lend themselves towards subcategorization of the industry in a way that provides better controls than the proposed approach. Therefore, NWQIs are not an appropriate basis for subcategorization.

CHAPTER 6

WASTEWATER CHARACTERIZATION AND MANURE CHARACTERISTICS

6.0 INTRODUCTION

This chapter describes waste streams generated by the animal feeding industry. Differences in waste composition and generation between animal types within each sector are highlighted.

The types of animal production and housing techniques determine whether the waste will be managed as a liquid, semisolid, or solid (Figure 6-1).The type of manure and how it is collected has a direct impact on the nutrient value of the waste, its value as a soil amendment, or other uses.

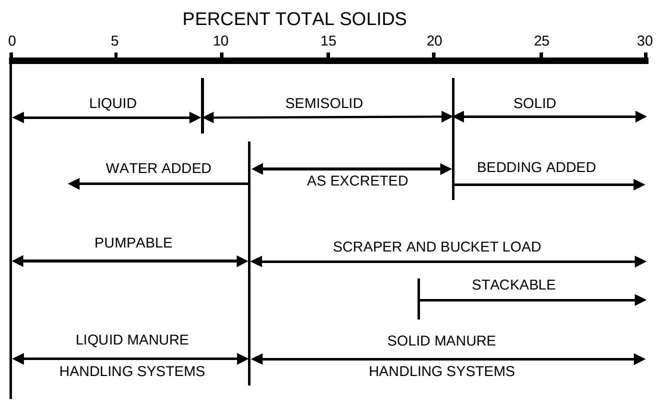

Figure 6-1.Manure characteristics that influence management options (after Ohio State University Extension, 1998).

6.1 Swine Waste

Swine waste contains numerous chemical and biological constituents such as nutrients, heavy metals, and pathogens that can potentially contaminate the environment. The composition of swine waste and the rate of its excretion by the pig varies with the stage of physical development, the pig’s gender, and for females, whether she is farrowing. As noted in Chapter 4, during the course of their life cycle, pigs receive up to six different diets to maximize growth at each stage of physical development. Each diet is composed of a unique mix of nutrients and minerals, and these different diets are reflected in the different composition of manure generated.

Swine waste also undergoes physical and chemical changes after it has been excreted by the pig. For example, swine waste volume and composition change after the waste becomes mixed with water, feed, and bedding materials. Furthermore, microbial activity alters the chemical makeup of the waste by metabolizing organic matter and generating chemical by-products. Additional chemical changes can occur depending on how the waste is stored and whether it is treated.

For swine operations, typical manure-handling practices are designed to produce either a liquid or a semisolid. Thus, the nutrient component of manure usually becomes more dilute because of the addition of water used to aid in collection of the manure. In addition, ammonia volatilization reduces nitrogen (N) concentrations in both liquid and dry manure-handling systems. Phosphorus (P) concentrations increase in manure that is handled dry because the water content decreases.

As discussed in Chapter 4, swine manure is typically collected and stored by means of pit storage, lagoons, or a combination of the two. Most lagoons operate anaerobically. Aerated lagoons have received less attention because of their higher costs; however, their potential for decreased odor might increase their use. Svoboda (1995) achieved N removal, ranging from 47 to 70 percent (depending on aeration), through nitrification and denitrification in an aerobic treatment reactor using whole pig slurry. The proportion of P and potassium (K) typically remaining after storage is higher than N. However, up to 80 percent of the P in lagoons is found in the bottom sludge versus the water fraction (MWPS, 1993).

Jones and Sutton (1994) analyzed manure nutrient content in liquid manure pit and anaerobic lagoon samples just before land application. On a mass basis for pit storage, N decreases ranged from 11 to 47 percent; P, 9 to 67 percent; and K, 5 to 42 percent. In the water fraction of lagoons, N decreases ranged from 76 to 84 percent; P, 78 to 92 percent; and K, 71 to 85 percent. Nitrogen decreases in these two storage systems were primarily due to volatilization, whereas P and K decreases were due to accumulation in sludge. Boland et al. (1997) found that for deep pit systems almost four times as much land was needed when applying manure based on P rather than N, 2.5 times for tank storage, and 1.7 times for lagoon systems. These differences can be attributed to less ammonia volatilization in deep pit systems, and solids settling in lagoons.

A field study of Missouri swine lagoon surface-to-volume ratios found that large swine lagoons have significantly higher total N concentrations than small lagoons. This finding suggests that nutrient concentrations, and thus land application, of treated swine manure should be based on the design and performance characteristics of the lagoon rather than on manure production alone (Fulhage, 1998).

The use of evaporative lagoon systems has increased in arid regions. These systems rely on evaporation to reduce wastewater with pollutants accumulating in the lagoon sludge. This approach results in reduced or no land application of wastes. For example, due to a lack of adequate land disposal area in Arizona, Blume and McCleve (1997) increased the evaporation of wastewater from a 6,000-hog flush/lagoon treatment system by spraying the wastewater into the air. Although information on volatilization was not available, the evaporative increase from spraying and pond evaporation, versus pond evaporation alone, was 51 percent.

The following sections characterize swine waste in terms of generation rates, and chemical and biological contaminants. Differences between swine types and operations and changes to the waste after it leaves the pig are also characterized.

6.1.1 Quantity of Manure Generated

Table 6-1 shows the quantity of manure generated by different types of swine. Variation in these quantities can be attributed to different ages and sizes of animals within a group (USDA, 1992). Manure production can also vary depending on the digestibility of feed rations. For example, corn, which is 90 percent digestible, results in less total solids in manure than a less digestible feed such as barley, which is 70 percent digestible (USDA, 1992).

Table 6-1. Quantity of Manure Excreted by Different Types of Swine.

<table>
<tr><th rowspan="2">Type of Swine</th><th colspan="4">Manure Mass (lb/yr/1,000 lb of animal mass)</th></tr>
<tr><th>Maximum Reported</th><th>Minimum Reported</th><th colspan="2">USDA 1998 Value</th></tr>
<tr><td>Grower-Finisher</td><td>44,327[a]</td><td>14,600[a]</td><td rowspan="2">Grower-Finisher 29,380[d]</td><td rowspan="7">Farrow to Finish 38,940[e]</td></tr>
<tr><td>Replacement Gilt</td><td>29,872[a]</td><td>11,972[a,b]</td></tr>
<tr><td>Boar</td><td>31,527[a]</td><td>7,483[b]</td><td rowspan="4">Farrow 12,220[d]</td></tr>
<tr><td>Gestating Sow</td><td>18,250[a]</td><td>9,928[b]</td></tr>
<tr><td>Lactating Sow</td><td>32,120[a]</td><td>21,900[a,b]</td></tr>
<tr><td>Sow and Litter</td><td>21,900[c]</td><td>21,900[c]</td></tr>
<tr><td>Nursery Pig</td><td>54,142[a]</td><td>23,981[c]</td><td>---</td></tr>
</table>

[a]NCSU, 1994.
[b]USDA, 1992.
[c]MWPS, 1993.
[d]USDA, 1998.
[e]Adapted from USDA, 1998.
---Not available.

As described in Chapter 3, there are three stages of swine production—farrow, nursery, and grower-finisher. Some swine operations encompass all three stages, whereas others specialize in just one. This section discusses the type of animal included in each operation and summarizes data on the quantity of manure produced by different operations.

Farrowing Operations

Farrowing operations include boars, gestating sows, lactating sows, and the sows' litters. Newborn pigs remain at the farrowing facility until they are weaned, which typically takes 3 to 4 weeks. Lactating sows and their litters produce the most manure, whereas boars produce the least. Manure production values for 1,000 lbs of animal in a farrowing operation range from 7,483 (USDA, 1992) to 32,120 lb/yr (NCSU, 1994), as shown in Table 6-2.

Nursery Operations

After farrowing and weaning, young pigs are moved to a nursery, when they reach approximately 15 pounds. They remain in the nursery for 7 to 8 weeks until they weigh approximately 60 pounds and are then transferred to a grower-finisher operation. Nursery pigs produce manure at rates of 23,981 (MWPS, 1993) to 54,142 lb/yr per/1,000 lbs of animal (NCSU, 1994) (Table 6-2).

Table 6-2. Quantity of Nitrogen Present in Swine Manure as Excreted.

	Nitrogen (lb/yr/1,000 lb of animal mass)		
Operation Type	**Maximum Reported**	**Minimum Reported**	**USDA 1998 Value**
Farrow to Finish	NA	NA	220.0[c]
Grower-Finisher	228.8[a]	87.6[b]	166.0[d]
Farrow	214.0[a]	54.8[b]	81.0[d]
Nursery	224.1[a]	134.0[a]	—

[a]NCSU, 1994.
[b]USDA, 1992.
[c]Adapted from USDA, 1998.
[d]USDA, 1998.
NA Not available.

Grower-Finisher Operations

In a finishing operation pigs are raised to market weight, which is approximately 240 to 280 pounds. This third stage of swine production is typically 15 to 18 weeks long, after which finished hogs are sent to market at approximately 26 weeks of age. A grower-finisher operation raises pigs over a relatively long period of time, during which their weight changes substantially. This weight change affects the quantity of manure produced (USDA, 1992). Values for manure production from growing-finishing pigs range from 11,972 (USDA, 1992) to 44,327 lb/yr per 1,000 lbs of animal (NCSU, 1994) (Table 6-2).

Farrow-to-Finish Operations

A farrow-to-finish operation includes all three stages of swine production. Because of the large variability in animal types presented in this type of operation, manure production values vary widely, from 7,483 lb/yr per/1,000 lbs of animal for boars (USDA, 1992) to 54,142 lb/yr per 1,000 lbs of animal for nursery pigs (NCSU, 1994) (Table 6-1).

6.1.2 Description of Waste Constituents and Concentrations

Swine waste contains substantial amounts of N, P, K, pathogens, and smaller amounts of other elements and pharmaceuticals. This section provides a summary of the constituents of swine waste as reported in the literature. There is significant variability in the generation rates presented below. This variability can be attributed to different nutritional needs for swine in the same operation type (e.g., sows and boars), and for swine of different ages and sizes grouped in the same operation. Also, as shown earlier in Table 6-1, different types of swine produce different quantities of manure.

Nitrogen

Nitrogen is usually measured as total N or as total Kjeldhal nitrogen (TKN). Although TKN does not include nitrate-nitrogen (NO_3-N), it may be considered equal to total N because NO_3-N is present only in very small quantities in swine manure (0.051 to 1.241 lb/yr per 1,000 lbs of animal) (NCSU, 1994; USDA, 1998). Published values for N production in swine manure range from 54.8 (USDA, 1992) to 228.8 lb/yr per 1,000 lbs of animal (NCSU, 1994), as shown in Table 6-2. In general, boars produce the least amount of N per 1000 pounds of animal, and grower-finisher pigs produce the most.

Phosphorus

The quantity of P excreted in swine manure for different types of swine operations is shown in Table 6-3. Phosphorus content ranges from 18.3 (USDA, 1992) to 168.2 lb/yr per 1,000 lbs of animal (NCSU, 1994)—boars excrete the least amount of P in manure per 1000 pounds of animal, whereas grower-finisher pigs excrete the most.

Table 6-3. Quantity of Phosphorus Present in Swine Manure as Excreted.

	Phosphorus (lb/yr/1,000 lb of animal mass)		
Operation Type	**Maximum Reported**	**Minimum Reported**	**USDA 1998 Value**
Farrow to Finish	NA	NA	64.1[d]
Grower-Finisher	168.2[a]	29.2[b]	48.3[e]
Farrow	68.3[a]	18.3[b]	26.2[e]
Nursery	93.4[a,b]	54.6[c]	—

[a]NCSU, 1994.
[b]USDA, 1992.
[c]MWPS, 1993.
[d]Adapted from USDA, 1998.
[e]USDA, 1998.
NA Not available.

Potassium

Table 6-4 shows the range of measured K quantities in manure for each type of swine operation. Boars produce the least amount of K at 36.50 lb/yr per 1,000 lbs of animal (USDA, 1992), whereas grower-finisher pigs produce the most at 177.4 lb/yr per 1,000 lbs of animal (NCSU, 1994).

Table 6-5 shows differences in the quantity of nutrients in manure at different stages of storage and handling. The data show a decrease in nutrient quantities from a manure slurry, which is untreated, to lagoon liquid and finally to secondary lagoon liquid. Lagoon sludge contains less N and K but more P, than lagoon liquid , because tends to be associated with the particulate fraction of manure, and N and K are usually in dissolved form. Table 6-6 shows the percent of manure nutrient content as excreted that is retained using different manure management systems. Table 6-7 shows manure nutrient concentrations in pit storage and anaerobic lagoons.

Table 6-4. Quantity of Potassium Present in Swine Manure as Excreted.

Operation Type	Potassium (lb/yr/1,000 lb of animal mass)		
	Maximum Reported	Minimum Reported	USDA 1998 Value
Farrow to Finish	NA	NA	154.79[d]
Grower-Finisher	177.4[a]	47.45[b]	116.79[e]
Breeder	136.6[a]	36.50[b]	47.96[e]
Nursery	130.6[a]	103.88[c]	---

[a]NCSU, 1994.
[b]USDA, 1992.
[c]MWPS, 1993.
[d]Adapted from USDA, 1998.
[e]USDA, 1998.
NA Not available.

Table 6-5. Comparison of Nutrient Quantity in Manure for Different Storage and Treatment Methods.

Nutrient	Mean Quantity in Manure (lb/yr/1000 lb of animal mass)					Land-Applied Quantity After Losses[b]	
	Paved Surface Scraped Manure[a]	Liquid Manure Slurry[a]	Anaerobic Lagoon Liquid[a]	Anaerobic Secondary Lagoon Liquid[a]	Anaerobic Lagoon Sludge[a]	Farrow	Grower
Nitrogen	137.65	164.44	34.71	28.79	6.57	20.29	17.23
Phosphorus	61.05	51.28	6.06	4.47	6.18	22.12	17.11
Potassium	79.81	78.20	29.84	23.13	1.46	43.01	43.75

[a]NCSU, 1994.
[b]USDA, 1998.

Table 6-6. Percent of Original Nutrient Content of Manure Retained by Various Management Systems.

Management System	Nitrogen	Phosphorus	Potassium
Manure stored in open lot, cool humid region.	55-70	65-80	55-70
Manure liquids and solids stored in an uncovered, essentially watertight structure.	75-85	85-95	85-95
Manure liquids and solids (diluted less than 50%) held in waste storage pond.	70-75	80-90	80-90
Manure stored in pits beneath slatted floor.	70-85	90-95	90-95
Manure treated in anaerobic lagoon or stored in waste storage pond after being diluted more than 50%.	20-30	35-50	50-60

Source: Adapted from Jones and Sutton, 1994.

Metals and Other Elements

Other elements present in manure include the micronutrients calcium, chlorine, magnesium, sodium, and sulfur; and heavy metals such as arsenic, cadmium, iron, lead, manganese, and nickel. Many of these elements are found in swine feed; others, such as heavy metals, are found in pharmaceutical feed additives. Table 6-8 shows the range of quantities of these elements in manure as excreted, after storage, at different stages of treatment, and when it is land applied.

Swine manure contains many kinds of bacteria, several of which are naturally present in the digestive systems of the animals. Others are in the pigs' general environment and can be ingested but are not a necessary component of digestion. Table 6-9 presents a summary of measured values of these bacteria in swine manure as excreted, and at various stages of treatment.

Table 6-7. Nutrient Concentrations for Manure in Pit Storage and Anaerobic Lagoons for Different Types of Swine.

Animal Type	Manure Produced 1000 gal/yr	Nitrogen (N) lb N/1000 gal/yr	Phosphorus (P) lb P/1000 gal/yr	Potassium (K) lb K/1000 gal/yr
Pit Storage				
Grower-Finisher	0.53	32.75	11.55	22.41
Lactating Sow	1.4	15.00	5.25	9.13
Gestating Sow	0.5	25.00	13.55	22.41
Nursery	0.13	25.00	8.44	18.26
Anaerobic Lagoon				
Grower-Finisher	0.95	5.60	1.639	3.486
Lactating Sow	2.10	4.10	0.874	1.660
Gestating Sow	0.90	4.40	1.857	3.320
Nursery	0.22	5.00	1.398	2.656

Source: Adapted from Jones and Sutton, 1994.

Table 6-8. Comparison of the Mean Quantity of Metals and Other Elements in Manure for Different Storage and Treatment Methods.

Element	Quantity produced in manure (lb/yr/1000 lb animal mass)					
	As Excreted	Paved Surface Scraped Manure[a]	Liquid Manure Slurry[a]	Anaerobic Lagoon Liquid[a]	Anaerobic Secondary Lagoon Liquid[a]	Anaerobic Lagoon Sludge[a]
Aluminum	1.340[a]	0.797	3.289	0.176	---	---
Arsenic	0.252[a]	---	0.003	0.004	---	---
Boron	1.132[b]-1.232[a]	0.239	0.086	0.042	0.037	0.004
Cadmium	0.010[a,b]	0.001	0.002	0.002	---	0.001
Calcium	120.45[b]-121.468[a]	117.932	48.433	7.547	6.459	6.373
Chlorine	93.335[a]-94.9[b]	90.615	27.073	18.571	---	0.378
Cobalt	0.014[a]	0.013	---	0.002	---	---
Copper	0.437[a]-0.438[b]	0.960	0.665	0.073	0.036	0.082
Chromium	---	---	---	---	---	0.007
Iron	5.84[b]-6.606[a]	16.858	4.643	0.486	0.292	0.713
Lead	0.030[a]-0.031[b]	0.019	---	0.033	---	0.007
Magnesium	25.55[b]-27.064[a]	33.766	16.884	2.461	1.587	1.837
Manganese	0.640[a]-0.694[b]	4.573	0.790	0.055	0.022	0.082
Molybdenum	0.010[a,b]	0.001	---	0.001	---	0.003
Nickel	0.029[a]	0.048	0.016	0.130	---	0.003
Selenium	---	---	---	0.000	---	---
Sodium	23.980[a]-24.455[b]	24.536	18.148	10.396	---	0.536
Sulfur	27.192[a]-27.74[b]	24.791	14.702	2.089	1.542	1.333
Zinc	1.825[b]-1.855[a]	2.414	2.210	0.191	0.036	0.212

[a]NCSU, 1994.
[b]ASAE, 1998.
NA Not available.

Table 6-9. Comparison of the Mean Concentration of Pathogens in Manure for Different Storage and Treatment Methods.

Type of Bacteria	Quantity Present in Manure (bacterial colonies per pound of manure)				
	Manure As Excreted	Paved Surface Scraped Manure	Liquid Manure Slurry	Anaerobic Lagoon Liquid	Anaerobic Lagoon Sludge
Enterococcus bacteria	3.128E+09	1.395E+09	3.839E+09	1.232E+06	---
Escherichia coliform bacteria	4.500E+07	5.400E+07	1.302E+08	---	---
Facultative bacteria	---	5.400E+11	5.164E+11	---	---
Fecal coliform bacteria	1.106E+09	4.800E+08	1.777E+07	2.502E+06	---
Fecal streptococcus bacteria	2.873E+10	---	2.276E+07	2.285E+06	---
Streptococcus bacteria	1.980E+08	2.205E+10	1.995E+10	---	---
Total aerobic bacteria	---	2.745E+11	1.269E+11	---	---
Total anaerobic bacteria	---	5.400E+11	1.092E+11	---	---
Total bacteria	---	---	---	3.885E+08	7.769E+09
Total coliform bacteria	2.445E+09	1.598E+09	9.551E+07	1.083E+07	---

Source: NCSU, 1994.
NA Not available.

Pharmaceuticals

To promote growth and to control the spread of disease, antibiotics and other pharmaceutical agents are often added to feed rations. Many of these chemicals are transformed or broken down through digestion and their components are excreted in manure. Table 6-10 lists several common pharmaceuticals added to swine feed and their frequency of use as reported in *Swine '95 Part I: Reference of 1995 Swine Management Practices* (USDA APHIS, 1995).

Table 6-10. Type of Pharmaceutical Agents Administered in Feed, Percent of Operations that Administer them, and Average Total Days Used.

Antibiotic/Agent in Feed	Percent Operations	Standard Error	Average Total Number Days	Standard Error
Chlortetracycline/Sulfathiazole/Penicillin	6.7	2.1	33.8	5.3
Chlorotetracycline/Sulfamethazine/Penicillin	6.4	2.0	23.6	3.6
Tylosin/Sulfamethazine	4.8	2.1	45.6	4.1
Carbadox	12.4	2.5	31.2	2.1
Lincomycin	4.3	1.4	60.3	17.6
Apramycin	2.8	1.2	50.9	22.7
Chlortetracycline	41.1	4.0	58.1	4.6
Oxytetracycline	9.6	2.2	39.2	6.6
Neomycin/Oxytetracycline	10.4	3.0	55.3	14.6
Tylosin	30.4	3.7	57.4	5.1
Bacitracin (BMD)	52.1	4.1	72.2	4.0
Virginiamycin	3.8	1.3	65.1	11.6
Zinc oxide	5.0	2.1	81.2	22.9
Copper sulfate	6.1	1.9	62.8	11.3
Other	4.6	2.2	97.6	11.8

Source: USDA APHIS, 1995.

Physical Characteristics

Tables 6-11 and 6-12 list several characteristics of swine manure as excreted by pigs, classified by different operation types, and with different types of storage and treatment methods.

Table 6-11. Physical Characteristics of Swine Manure by Operation Type and Lagoon System.

Characteristic	Physical Characteristics in Swine Manure (lb/yr/1000 lb unless otherwise noted)						
	Grower-Finisher as Excreted	Farrow as Excreted	Farrow Finish as Excreted	Liquid Manure Slurry[b]	Anaerobic Lagoon Sludge[b]	Anaerobic Lagoon Liquid[b]	Anaerobic Secondary Lagoon Liquid[b]
Manure	11,972[a]–33,830[b]	7,483[a]–27,313[b]	7,483[a]–39,586[b]	6,205	270	7,381	7,381
Urine	42.1[b]–49.0[b]	---	39.0[b]–74.0[b]	---	---	---	---
Density (lb/ft^3)	61.8[b]–62.8[b]	---	61.3–62.8	8.4	8.9	8.4	8.35
Moisture (%)	90[a]–91[a]	90[a]–97[a]	90[a]–97[a]	---	92[a]	100[a]	---
Total solids	3.28[a]–6.34[a]	1.9[a]–6.0[a]	1.9[a]–11.0[a]	---	7.60%[c]	0.25%[c]	---
Total dissolved solids	1.29[a]	---	1.29[a]	---	---	---	---
Volatile solids	2.92[a]–5.40[a]	1.00–5.40	1.00–8.80	---	379.89 [c] lb/1000 gal	10.00 [c] lb/1000 gal	---
Fixed solids	0.36[a]–0.94[a]	0.30[a]–0.60[a]	0.30[a]–1.80[a]	---	253.27 [c] lb/1000 gal	10.83 [c] lb/1000 gal	---
C:N ratio	6[a]–7[a]	3[a]–6[a]	3[a]–8[a]	---	8[a]	---	2[a]

[a]USDA, 1992.
[b]NCSU, 1994.
[c]USDA, 1996.
C Carbon

Table 6-12. Physical Characteristics of Different Types of Swine Wastes.

Physical Characteristic	lb/yr/1000 lb	lb/ 1000 gallons	
	Paved Surface Scraped Manure[a]	Feedlot Runoff Water[b]	Settling Basin Sludge[b]
Manure	21,089	---	---
Density (lb/ft^3)	62.4	---	---
Moisture (%)	---	98.50	88.8
Total solids	---	1.50	11.2

[A]NCSU, 1994
[b]USDA, 1996

6.2 Poultry Waste

Poultry wastes differ in composition between the three bird types addressed in this document — layers, broilers, and turkeys. Each bird type is raised for a specific role and is provided with a diet tailored to its nutritional needs. Hence, layers are fed diets to maximize egg production, whereas broilers are fed diets to promote growth and development. Within each subsector, however, variation in manure composition as excreted is quite small due to the high degree of integration, use of standardized feed, and total confinement (USEPA, 1999). However, there are differences in composition and quantity generated between operations due to variations in length and type of manure storage employed by the operation.

Broilers and turkeys have similar production regimes in terms of manure production, manure handling, and nutrient recovery. The floor of the house is covered with a bedding material that absorbs liquid. During the growth of the flock, continuous air flow removes ammonia and other gasses resulting in lower N content of the litter (manure and bedding). Another result of continuous air flow is a reduction in the moisture content of the litter over that of freshly excreted manure.

Manure produced by the laying industry typically includes no bedding. Two main types of manure handling are handling as excreted manure (with no bedding), and water-flushed collection. In high-rise cages or scrape-out/belt systems, manure is excreted onto the floor below with no bedding to absorb moisture. The ventilation system dries the manure as it is stored. Nutrients are more concentrated without bedding than with bedding. Flushing layer manure with water results in diluted nutrient concentrations, but increases the amount of waste that must be disposed.

As shown in Table 6-13, manure generation rates differ considerably between layers and broilers. The maximum reported generation rate for broilers is over 30 percent greater than for layers. Pullets have the lowest generation rate — almost half the rate of manure production for broilers, and only 70 percent of the production rate for layers.

Table 6-13. Quantity of Manure Excreted for Broilers.

Manure Mass (lb/yr/1,000 lb of animal mass)		
Minimum Reported	**Maximum Reported**	**USDA 1998 Value**
25,550[a]	31,025[b]	29,940[c]

[a]MWPS, 1993.
[b]ASAE, 1998.
[c]USDA, 1998.

6.2.1 Broiler Waste Characteristics

6.2.1.1 Quantity of Manure Generated

Manure production is frequently presented as volume or weight of manure produced per 1,000 pounds of animal mass. There is significant variation between the minimum and maximum reported values for manure generation in broilers. Table 6-13 contains the minimum, maximum, and 1998 USDA reported values for manure generation rates for broilers. The 1998 USDA reported values were used in EPA's analyses.

6.2.1.2 Description of Waste Constituents and Concentrations

Broiler waste contains N, P, K, and smaller amounts of other elements and pathogens. This section provides a summary of the constituents of broiler manure and litter as reported in the literature.

Table 6-14 shows selected physical and chemical characteristics for broiler manure as excreted, and after application of different storage practices. Manure quantity decreases under dry storage practices, especially when stored as a manure cake.

Table 6-14. Consistency of Broiler Manure as Excreted and for Different Storage Methods.

Physical Characteristic	Physical Characteristics of Manure (lb/yr/1,000 lb of animal mass unless otherwise noted)					
	As Excreted	**Broiler Litter[d]**	**Broiler House Litter[c]**	**Broiler House Manure Cake[c]**	**Broiler Litter Stockpile[c]**	**Broiler-Roaster House Litter[c]**
Manure/Litter	25,550[a]–31,025[b]	12,775	7,449	2,364	6,733	5,710
Density	63.0a–63.7[c]	---	31.7	34.3	33.1	29.0
Moisture	75d	24	---	---	---	---
Total solids	7,300d–8,030[b]	9,673	5,857	1,429	4,083	4,349
Volatile solids	5,475d–8,030[a]	7,811	4,666	1,110	2,903	3,349
Fixed solids	1,825[d]	1862	---	---	---	---
C:N ratio	8[d]	9	---	---	---	---

[a]ASAE, 1998.
[b]MWPS, 1993.
[c]NCSU, 1994.
[d]USDA, 1992.

Broilers excrete numerous nutrients including N, P, and K. As shown in Table 6-15, N is excreted at the highest rate of the three nutrients. In general, broilers produce more N and K per pound of bird than do layers, although K production rates are nearly equivalent on a time-averaged basis (USDA, 1998). These levels are altered when manure is stored or treated. Liquid manure volumes and nutrient concentrations are presented in Table 6-16 for raw and stored manure. Table 6-17 shows nutrient production as excreted and after loses. Storage as a manure cake significantly reduces nutrient content, especially N. Table 6-18 shows metals in broiler manure as excreted and for different storage and treatment methods. Microbial populations are very active in broiler litter and include enterococcus, fecal coliform, salmonella, and streptococcus. Table 6-19 shows bacteria levels per pound of manure.

Table 6-15. Nutrient Quantity in Broiler Manure as Excreted.

Nutrient	Quantity Present in Manure (lb/yr/1,000 lb of animal mass)		
	Minimum Reported	Maximum Reported	Time-Averaged Value
Nitrogen	310.25[a]	401.50b,[c]	401.65[e]
Phosphorus	71.68[a]	124.10[b]	116.77[e]
Potassium	139.27[d]	167.90[b]	157.04[e]

[a]MWPS, 1993.
[b]USDA, 1992.
[c]ASAE, 1998.
[d]NCSU, 1994.
[e]USDA, 1998.

Table 6-16. Broiler Liquid Manure Produced and Nutrient Concentrations for Different Storage Methods.

Storage Method	Manure Produced (1000 gal/yr)	Nutrient Concentration (lb nutrient/1000 gal)		
		Nitrogen	Phosphorus	Potassium
Raw manure	0.006	130.4	36.3	44.3
Pit storage [a]	0.010	63.00	17.48	24.07
Anaerobic lagoon storage [b]	0.016	8.50	1.88	2.91

Source: MWPS, 1993 as presented by Jones and Sutton, 1994.
[a] Includes dilution water.
[b] Includes rainfall and dilution water.

Table 6-17. Nutrient Quantity in Broiler Manure Available for Land Application or Utilization for Other Purposes

Nutrient	Quantity Present in Manure As Excreted and After Losses (lb/yr/1,000 lb of animal mass)	
	As Excreted	After Losses[a]
Nitrogen	410.6	241.0
Phosphorus	116.8	99.0
Potassium	157.0	141.9

Source: USDA NRCS, 2000.
[a] Manure nutrient losses during collection, storage, treatment, and transfer include volatilization of nitrogen, spillage, and manure nutrients carried from the confinement facilities by rainfall and runoff. Only waste treatment technologies that are in common practice were considered in estimating these losses.

Table 6-18. Quantity of Metals and Other Elements Present in Broiler Manure as Excreted and for Different Storage Methods.

Element	Quantity Present in Manure and Litter (lb/yr/1,000 lb of animal mass)				
	As Excreted	Broiler House Litter[a]	Broiler House Manure Cake[a]	Broiler Litter Stockpile[a]	Broiler-Roaster House Litter[a]
Aluminum	---	4.901	---	---	---
Arsenic	---	0.176	---	---	---
Barium	---	0.148	---	---	---
Boron	0.795[a]	0.211	0.052	0.131	0.133
Cadmium	0.017[a]	0.012	0.002	0.001	0.014
Calcium	136.626[a]–149.650[b]	158.424	40.197	212.888	117.184
Chlorine	296.537[a]	47.694	---	51.803	---
Cobalt	---	0.007	---	---	---
Copper	0.331[a]–0.358[b]	1.984	0.481	0.968	1.389
Chromium	---	0.566	0.185	0.006	0.942
Iron	29.509[a]	4.381	1.420	5.991	4.553
Lead	0.033[a]	0.151	0.054	---	0.204
Magnesium	50.336[a]–54.750[b]	32.871	8.225	27.596	24.046
Manganese	2.378[a]	2.957	0.815	2.344	2.170
Mercury	---	0.001	---	---	---
Molybdenum	0.134[a]	0.003	0.001	0.002	0.002
Nickel	0.111[a]	0.427	0.217	0.008	0.352
Selenium	---	0.002	---	---	---
Silicon	---	5.323	---	---	---
Sodium	50.336[a]–54.750[b]	48.668	12.390	22.290	37.143
Strontium	---	0.339	---	---	---
Sulfur	28.763[a]–31.025[b]	45.749	10.876	33.892	39.229
Zinc	1.208[a]–1.314[b]	2.652	0.713	2.112	1.932

[a]NCSU, 1994.
[b]ASAE, 1998.

Table 6-19. Concentration of Bacteria in Broiler House Litter.

Parameter	Concentration of Bacteria (bacteria colonies/lb manure)
Total bacteria	4.775E+11
Total coliform bacteria	2.285E+06
Fecal coliform bacteria	7.758E+06
Streptococcus bacteria	6.728E+09
Salmonella	2.048E+06
Total aerobic bacteria	7.107E+09

Source: NCSU, 1994.

6.2.2 Layer Waste Characteristics

6.2.2.1 Quantity of Manure Generated

Manure production is frequently presented as volume or weight of manure produced per 1,000 pounds of animal mass. There is less variation between the minimum and maximum reported values for manure generation in layers than in broilers. Table 6-20 contains the minimum, maximum, and 1998 USDA reported values for manure generation rates for layers. The 1998 USDA reported values for manure generation were used in EPA's analyses.

Table 6-20. Quantity of Manure Excreted for Layers.

Manure Mass (lb/yr/1,000 lb of animal mass)		
Minimum Reported	**Maximum Reported**	**USDA 1998 Value**
19,163[a]	23,722[b]	22,900[c]

[a]MWPS, 1993.
[b]NCSU, 1994.
[c]USDA, 1998.

6.2.2.2 Description of Waste Constituents and Concentrations

Layer waste contains N, P, K, and smaller amounts of other elements and pathogens. This section provides a summary of the constituents of layer manure as reported in the literature. Table 6-21 shows selected physical and chemical characteristics for layer manure as excreted, and after application of different storage and treatment practices. Manure quantity decreases under dry storage practices but increases significantly when converted to a slurry, or stored and treated in an anaerobic lagoon.

Table 6-21. Physical Characteristics of Layer Manure as Excreted and for Different Storage Methods.

Physical Characteristic	Physical Characteristics of Manure (lb/yr/1,000 lb of animal mass unless otherwise noted)						
	As Excreted	**High-Rise Litter[d]**	**Paved Surface Scraped Manure[b]**	**Unpaved Deep Pit Stored Manure[b]**	**Liquid Manure Slurry[b]**	**Anaerobic Lagoon Liquid[b]**	**Anaerobic Lagoon Sludge[b]**
Manure	19,163[a]–23,722[b]	14126	9877	32534	53598	9881	98805
Density (lb/ft^3)	60.0[a,c]–65.1[d]	62.4	51.3	7.8	8.4	8.4	8.4
Moisture (%)	74.8[a]–75.0[d]	---	---	---	---	---	---
Total solids	5,512[d]–6,019[b]	4979	5216	3646	265	1633	1633
Total suspended solids	2,477[b]	---	---	748	101	---	---
Volatile solids	3,942[d]–4,440[b]	3483	3137	2401	119	722	722
Volatile suspended solids	481[b]–4,380[c]	---	---	637	52	---	---
Fixed solids	1,570[d]	---	---	---	---	---	---
C:N ratio	7[d]	---	---	---	---	---	---

[a]MWPS, 1993.
[b]NCSU, 1994.
[c]ASAE, 1998.
[d]USDA, 1992.

Layers excrete numerous nutrients including N, P, and K. As shown in Table 6-22, N is excreted at the highest rate of these three nutrients. Nutrient concentrations of liquid manure are shown in Table 6-23. Table 6-24 shows nutrient production after application of storage or treatment practices. Table 6-25 shows metals in layer manure as excreted, and for different storage and treatment methods.

Table 6-22. Quantity of Nutrients in Layer Manure as Excreted.

Nutrient	Quantity Present in Manure (lb/yr/1,000 lb of animal mass)		
	Minimum Reported	Maximum Reported	Time-Averaged Value
Nitrogen	264.63[a]	315.43[b]	308.35[d]
Phosphorus	99.55[a]	113.15[c]	114.27[d]
Potassium	106.05[a]	124.10[c]	119.54[d]

[a]MWPS, 1993.
[b]NCSU, 1994.
[c]USDA, 1992.
[d]USDA, 1998.

Table 6-23. Annual Volumes of Liquid Layer Manure Produced and Nutrient Concentrations.

Storage Method	Manure Produced (1000gal/yr)	Nutrient (lb nutrient/1000 gal)		
		Nitrogen	Phosphorus	Potassium
Raw manure	0.011	110.2	35.4	37.7
Pit storage [a]	0.017	60.00	19.67	23.24
Anaerobic lagoon storage [b]	0.027	7.00	1.75	2.91

Source: MWPS, 1993 as presented by Jones and Sutton, 1994.
[a] Includes dilution water.
[b] Includes rainfall and dilution water.

Table 6-24. Nutrient Quantity in Layer Litter for Different Storage Methods.

Nutrient	Quantity Present in Manure and Litter (lb/yr/1,000 lb of animal mass)					
	High-Rise Litter[a]	Paved Surface Scraped Manure[b]	Unpaved Deep Pit Stored Manure[b]	Liquid Manure Slurry[b]	Anaerobic Lagoon Liquid[b]	Anaerobic Lagoon Sludge[b]
Nitrogen	199.44	165.79	238.42	42.35	24.63	24.63
Phosphorus	97.60	110.21	94.55	4.77	39.87	39.87
Potassium	114.40	107.96	114.40	54.75	9.60	9.60

[a]USDA, 1992.
[b]NCSU, 1994.

Table 6-25. Quantity of Metals and Other Elements Present in Layer Manure as Excreted and for Different Storage Methods.

	Quantity Present in Manure and Litter (lb/yr/1,000 lb of animal mass)						
Element	As Excreted	High-Rise Litter[c]	Paved Surface Scraped Manure[a]	Unpaved Deep Pit Stored Manure[a]	Liquid Manure Slurry[a]	Anaerobic Lagoon Liquid[a]	Anaerobic Lagoon Sludge[a]
Aluminum	9.987[a]	2.161	---	4.039	---	---	---
Arsenic	0.050[a]	---	---	---	0.002	---	---
Boron	0.651[a]–0.657[b]	0.157	0.178	0.125	0.059	0.041	0.041
Cadmium	0.014[a,b]	0.001	---	---	0.000	0.007	0.007
Calcium	474.500[b]–491.891[a]	288.598	375.753	138.050	6.945	55.653	55.653
Chlorine	204.400[b]–242.608[a]	28.394	---	27.554	21.777	---	---
Cobalt	0.029[a]	---	---	---	---	---	---
Copper	0.303[b]–0.308[a]	0.244	0.285	0.302	0.030	0.167	0.167
Chromium	---	0.114	0.188	---	0.002	---	---
Iron	21.900[b]–24.143[a]	2.936	14.008	7.089	0.387	5.727	5.727
Lead	0.270[b]–0.274[a]	0.135	0.656	---	0.005	0.023	0.023
Magnesium	51.100[b]–51.129[a]	58.577	28.306	16.495	2.188	13.629	13.629
Manganese	1.945[a]–2.227[b]	2.032	2.165	1.579	0.044	1.896	1.896
Mercury	---	---	---	---	0.000	---	---
Molybdenum	0.109[a]–0.110[b]	0.002	0.002	---	---	---	---
Nickel	0.091[a,b]	0.351	0.418	---	0.075	0.029	0.029
Selenium	0.010[a]	---	---	---	---	---	---
Sodium	36.500[b]–43.292[a]	19.646	16.268	20.082	11.755	3.958	3.958
Sulfur	51.053[a]–51.100[b]	49.971	23.554	16.762	3.918	8.414	8.414
Zinc	1.640[a]–6.935[b]	2.162	1.721	1.609	0.100	1.346	1.346

[a]NCSU, 1994.
[b]ASAE, 1998.
[c]USDA, 1992.

Microbial populations are quite active in layer litter and include enterococcus, fecal coliform, salmonella, and streptococcus. Table 6-26 shows bacteria levels per pound of manure. As shown in this table, converting the litter to a slurry substantially reduces the concentration of bacteria.

Table 6-26. Concentration of Bacteria in Layer Litter.

	Concentration in Manure (bacterial colonies/lb manure)	
Type of Bacteria	As Excreted	Layer Liquid Manure Slurry
Enterococcus bacteria	2.786E+13	---
Fecal coliform bacteria	1.552E+13	1.058E+06
Fecal streptococcus bacteria	3.375E+13	---
Salmonella	1.327E+10	---
Streptococcus bacteria	6.237E+13	---
Total aerobic bacteria	8.568E+15	---
Total bacteria	9.716E+16	---
Total coliform bacteria	1.835E+14	7.547E+06
Yeast	1.327E+15	---

Source: NCSU, 1994.

6.2.3 Turkey Waste Characteristics

Turkey operations usually separate and handle the birds in groups according to age, gender, size, or special management needs such as hatcheries or breeder farms. The types of animals are

- Poults (young turkeys)
- Turkey hens for slaughter
- Turkey toms for slaughter
- Hens kept for breeding

Although three major strains of turkeys are grown, the high degree of industry integration, standardized feed, and complete confinement has resulted in very little variation in manure characteristics. The exact quantity and composition of manure depends mostly on the specifics of farm management, such as precision feeding, control of wasted feed, and ammonia volatilization losses. Litter characteristics also vary according to material used for bedding.

6.2.3.1 Quantity of Manure Generated

Manure production is frequently presented as volume or weight of manure produced per 1,000 pounds of animal mass. Table 6-27 shows manure production as excreted for turkey hens for breeding and turkey hens and toms for slaughter.

Table 6-27. Annual Fresh Excreted Manure Production (lb/yr/1,000 lb of animal mass).

Animal Type	Range of Annual Manure Production Values	USDA 1998 Value
Turkeys for slaughter	15,914[a]-17,155[b]	16,360[c]
Hens for breeding		18,240[c]

[a]USDA, 1992.
[b]ASAE, 1998.
[c]USDA, 1998.

6.2.3.2 Description of Waste Constituents and Concentrations

Turkey waste contains N, P, K, and smaller amounts of other elements and pathogens. This section provides a summary of the constituents of turkey manure and litter as reported in the literature.

Composition of Manure

Exact manure composition depends on length and type of storage, as well as other management practices specific to each farm. Table 6-28 shows nutrients in turkey manure as excreted. Turkeys for slaughter produce more N and K in fresh, excreted manure, and breeding hens produce more P.

Table 6-28. Quantity of Nutrients Present in Fresh, Excreted Turkey Manure (lb/yr/1,000 lb of animal mass).

Animal Type	Nitrogen		Phosphorus		Potassium	
	Range Includes Minimum	Maximum Reported	Minimum Reported	Range Includes Maximum	Range Includes Minimum	Maximum Reported
Turkeys for slaughter	248.34[a]	270.1[b]	84[c]	96.77[a]	94.97[a]	102.20[b]
Hens for breeding	204.38[a]			120.48[a]	69.31[a]	

[a]USDA, 1998.
[b]USDA, 1992.
[c]ASAE, 1998.

Composition of Litter

The nutrient content of turkey litter is usually lower than that for broiler litter, and brooder litter contains less manure nutrients than grower house litter. Exact manure composition depends on length and type of storage, as well as other management practices specific to each farm. After stockpiling, litter may lose up to half of the total N excreted. When manure is combined with bedding materials, the waste litter absorbs water content from the manure. Table 6-29 displays the water absorption capacity of commonly used bedding materials. Because of different types of litter composition for turkey operations, nutrient quantities per ton of litter vary (Table 6-30).

Table 6-29. Water Absorption of Bedding.

Bedding Material	Pounds of Water Absorbed per Pound of Bedding
Wood	
Tanning Bark	4.00
Fine Bark	2.50
Pine	
Chips	3.00
Sawdust	2.50
Shavings	2.00
Needles	1.00
Hardwood Chips, Shavings or Sawdust	1.50
Corn	
Shredded Stover	2.50
Ground Cobs	2.10
Straw	
Flax	2.60
Oats	
Combined	2.50
Chopped	2.40
Wheat	
Combined	2.20
Chopped	2.10
Hay, Chopped Mature	3.00
Shells, Hulls	
Cocoa	2.70
Peanut, Cottonseed	2.50
Oats	2.00

Source: MWRA, 1993.

Table 6-30. Turkey Litter Composition in pounds per ton of litter.[a]

Manure Type	Nitrogen	Phosphorus	Potassium
Brooder house litter after each flock [b]	45	23	27
Grower house litter after annual cleanout [b]	57	31	33
Stockpiled litter [b]	36	30[e]-31	25[e]-27
Tom growout [c]	52	33	35
Hen growout [c]	73	38	38
Brood house [d]	51	14	27
Growout house [d]	65	28[e]-31	33[e]-38

[a]Zublena, 1993.
[b]NCSU, 1999.
[c]Pennsylvania
[d]Arkansas
[e]NCSU, 1994.
P_2O_5 converted to P by multiplication of 0.437.
K_2O converted to P by multiplication of 0.83.

In those cases where litter is recycled from the brooder barn and used in the growout barn, nutrient values of litter increase to roughly 60 pounds of available N and P per ton of litter. Table 6-31 presents some metal components of turkey litter.

Table 6-31. Metal Concentrations in Turkey Litter (pounds per ton of litter).

Manure type	Ca	Mg	S	Na	Fe	Mn	B	Mo	Zn	Cu
Turkey, brooder	28.0	5.7	7.6	5.9	1.4	0.52	0.047	0.00081	0.46	0.36
Turkey, grower	42.0	7.0	10.0	8.4	1.3	0.65	0.048	0.00092	0.64	0.51

Source: NCSU, 1998.

The physical characteristics and nutrient content of turkey manure and litter types are variable. As seen in Table 6-32, manure characteristics differ significantly from litter characteristics.

Fresh manure contains more nutrients than manure cakes, but litter from grower houses may exceed fresh manure K amounts. Table 6-33 shows metal quantities in excreted turkey manure and litter types by gender and age of bird.

Table 6-32. Waste Characterization of Turkey Manure Types (lb/yr/1,000 lb of animal mass).

Parameter	Turkey fresh manure	Turkey hen house manure cake[a]	Turkey tom house manure cake[a]	Turkey house litter[a]	Turkey poult (brooder) house litter[a]	Turkey breeder house litter[a]	Turkey stockpiled litter[a]
Manure	15,914[c]–17,155[d]	1905.3	1905.3	---	---	---	---
Litter	---	---	---	5960.5	6953.25	4967.65	5420.25
Volume (ft^3/yr/1000 lb)	251.85[c]	---	---	---	---	---	---
Density (lb/ft^3)	63[d]–63.49[a]	32.3	---	---	22.91	62.43	24.1
Total Solids (%wb)	4,179[a]–4,380[d]	1041.6	1041.6	4365.4	5527.96	3893.35	3316.90
Volatile Solids (%db)	3,205[a]–3,541[c]	845.2	845.3	3182.8	4297.07	-	-
TKN	226.3[d]–231.0[a]	42.74	42.74	165.13	138.12	87.97	85.67
NO_3–N	-	-	-	0.40	1.31		1.31
P	84.0[d]–87.8[a]	19.38	19.38	82.38	65.77	51.17	82.42
K	83.2[a]–87.6[d]	23.69	23.69	98.77	77.64	37.05	67.74

[a] NCSU, 1994.
[b] USDA, 1998.
[c] USDA, 1992.
[d] ASAE, 1998.

Table 6-33. Metals and Other Elements Present in Manure (lb/yr/1,000 lb of animal mass).

Metals/ Elements	Turkey fresh manure	Turkey hen house manure cake[a]	Turkey tom house manure cake[a]	Turkey house litter[a]	Turkey poult (brooder) house litter[a]	Turkey breeder house litter[a]	Turkey stockpiled litter[a]
Calcium	223.205[a]-230.0[b]	25.003	25.003	112.165	91.871	178.376	120.888
Magnesium	25.649[a]-26.6[b]	5.11	5.11	22.083	17.849	11.498	19.199
Sulfur	25.887[a]	5.986	5.986	25.477	21.207	18.287	20.039
Sodium	23.172[a]-24.0[b]	5.256	5.256	22.703	162.06	10.622	15.367
Chlorine	16.8407[a]	---	---	35.186	6.278	---	21.608
Iron	26.556[a]-27.4[b]	1.168	1.168	4.176	6.935	2.519	5.585
Manganese	0.853[a]-0.9[b]	0.548	0.5475	2.3725	1.825	1.059	2.044
Boron	0.452[a]	0.037	0.0365	0.146	0.146	0.073	0.110
Molybdenum	0.076[a]	0.001	0.001	0.004	0.003	---	0.003
Aluminum	---	0.694	0.694	2.263	5.037	---	---
Zinc	5.127[a]-5.5[b]	0.438	0.438	1.971	1.606	1.241	1.716
Copper	0.252[a]-0.3[b]	0.475	0.475	1.789	1.351	0.986	1.132
Cadmium	0.009[a]	---	---	0.001	0.001	---	0.001
Nickel	0.063[a]	---	---	0.018	0.007	---	0.007
Lead	0.190[a]	---	---	---	---	---	---

[a]NCSU, 1994.
[b]ASAE, 1998.

Data on bacterial concentrations in turkey manure or litter are generally sparse. However, Table 6-34 shows concentrations of fecal coliform and total bacteria for manure and litter. Land-applied quantities of turkey manure nutrients are shown in Table 6-35.

Table 6-34. Turkey Manure and Litter Bacterial Concentrations (bacterial colonies per pound of manure).

Bacteria Type	Excreted Manure	House Litter
Fecal coliform bacteria	1.31E+08	---
Total bacteria	---	2.53E+12

Source: NCSU, 1994.

Table 6-35. Turkey Manure Nutrient Composition After Losses–Land-Applied Quantities.

	Manure Composition (lb/yr/1,000 lb of animal mass)		
Animal	Nitrogen	Phosphorus	Potassium
Turkeys for slaughter	132.35 (116.0)	82.29 (14.5)	85.40 (9.6)
Hens for breeding	102.14 (102.2)	102.42 (18.1)	62.38 (6.9)

Source: USDA, 1998.
In parentheses are the differences between fresh, excreted manure content and after losses content.

6.2.4 Duck Wastes

The housing floor design and age of the ducks dictate the amount of area required to raise each bird. Age groups are kept isolated, either in separate buildings or in the same buildings with solid partitions between them. It is common for the female ducks and male drakes to be reared together. Breeding ducks are kept in breeder houses similar to turkey pole-barns. The mature ducks are typically bred at a ratio of one drake to five or six ducks.

6.2.4.1 *Quantity of Manure Generated*

The amount of manure produced depends on the number of birds, the amount and type of feed, and the age of the birds. Table 6-36 presents estimates for manure production by ducks. Table 6-37 presents the breakdown of nutrients available in the manure.

Table 6-36. Approximate Manure Production by Ducks.

Animal Type	Market Weight (Lbs)	Feed Eaten/Animal (lbs/year)	Manure Produced (lbs/year/animal)
Duck	7	114	22.8

Source: Jordan and Graves, 1996.

Table 6-37. Breakdown of Nutrients in Manure.

Animal Type	% Water	% N	% P	% K
Duck	61	1.1	1.45	0.5

Source: Florida Agricultural Information Retrieval System, 1998.

6.2.4.2 *Description of Waste Constituents and Concentrations*

Generally, ducks raised on small farms are housed in barns or poultry sheds with packed earthen or concrete floors. Bedding, such as straw or wood shavings, is used to dry the manure. The manure is removed manually or with power equipment at different intervals depending on the number of ducks and the season. The manure is then stored temporarily on a concrete pad or in a shed and then land applied. Some operations compost the manure.

Duck wastes in large operations are normally handled as a solid. Older barns or structures with solid floors accumulate a manure-litter mix that is removed between flocks with skid steers or front-end loaders. The solid manure is transported to a storage structure or directly applied to land.

6.3 Dairy Waste

This section describes the characteristics of dairy manure and waste. In this section, manure refers to the combination of feces and urine. Waste refers to manure plus other material, such as hair, bedding, soil, wasted feed, and water that is wasted or used for sanitary and flushing purposes. Due to the nature of dairy operations, however, even fresh manure may also contain small amounts of hair, bedding, soil, feed, and water.

6.3.1 Quantity of Manure Generated

Numerous analyses have estimated average manure quantities from dairy cattle. Four major data sources that contain mean values for dairy manure characteristics are identified below:

- ASAE Standard D384.1: *Manure Production and Characteristics*, 1999. This data source contains national fresh (as-excreted) manure characteristic values by animal type (e.g., dairy, beef, veal, swine).
- USDA, *Agricultural Waste Management Field Handbook (AWMFH)*, Chapter 4, 1996. This data source contains national manure characteristic values for fresh and managed manure (e.g., lagoon supernatant, feedlot runoff) by animal type including subtypes such as lactating and dry cows.
- NCSU, *Livestock Manure Production and Characterization in North Carolina*, 1994. This data source contains regional manure characteristic values for fresh and managed manure by animal type including subtypes.
- MWPS, *Livestock Waste Facilities Handbook*, 1985. This data source contains national fresh manure characteristic values by animal type and animal weight.

An analysis conducted by Charles Lander et al. of the USDA NRCS used a composite of three of these four data sources (Lander et al., 1998). Lander removed ASAE data before averaging to prevent double counting of the ASAE information that is included in the MWPS data. This analysis assumed that the average weight of a lactating cow is 1,350 pounds. EPA used data from the Lander analyses in estimating compliance cost for beef feedlots and dairies to be consistent with other USDA data used in the costing analyses. Table 6-38 presents the fresh manure estimates from all of these data sources for mature lactating dairy cows and calves.

Table 6-38. Weight of Fresh Dairy Manure.

Data Source	Quantity of Manure (wet basis) (lb/day/1,000-lb animal)	
	Lactating Cow	**Calf**
ASAE Standard	86	ND
USDA *Agricultural Waste Management Field Handbook*	80	ND
NCSU, *Livestock Manure Production and Characterization in North Carolina*	87.3	65.8
MWPS *Livestock Waste Facilities Handbook*	86	ND
USDA Lander analysis	83.5	ND

ND No data.

6.3.2 Waste Constituents and Concentrations

The composition and concentration of dairy waste varies from the time that it is excreted to the time it is ultimately used as a fertilizer or soil amendment. Nutrients and metals are expected to be present in dairy waste due to the constituents of the feed.

6.3.2.1 Composition of Fresh Manure

Manure characteristics for dairy cattle are highly variable and can be affected by the following: animal size, breed, and age; management choices; feed ration; climate; and milk production. For example, dairy feeding systems and equipment often produce considerable feed waste, which in most cases is added to the manure. In addition, dairy stall floors are often covered with organic and inorganic bedding materials (e.g., hay, straw, wood shavings, sawdust, soil, sand, ground limestone, dried manure) that improve animal comfort and cleanliness. Virtually all of this material will eventually be pushed, kicked, and carried from the stalls and added to the manure, and their characteristics imparted into the manure (Lander et al., 1998). In addition, the nutrient content (N, P, and K) of dairy manure can vary significantly due to differences in voluntary feed intake, differing supplemental levels, and differing amounts of nutrients removed during milking (USDA, 1992). Table 6-39 presents averages for fresh mature dairy cow and heifer manure characteristics that are reported in the four major data sources identified in Section 6.3.1. Data are presented for 16 nutrients and metals found in fresh dairy manure. Nitrogen is present in manure in four forms: ammonium-N, nitrate-N, nitrite-N, and organic-N. The total N is the sum of these four components, while the TKN is the sum of the organic-N and ammonium-N.

Phosphorus is present in manure in inorganic and organic form and presented as total P. Colonies of the pathogens coliform and streptococcus bacteria have also been identified in dairy manure.

Table 6-39. Fresh Dairy Manure Characteristics Per 1,000 Pounds Live Weight Per Day.

Parameter	Mean (mature dairy cow/dry cow)			
	ASAE	USDA	NCSU	MWPS
Moisture (%)	87.2	87.5/88.4	ND	87.3
Total solids (lb)	12	10 9.5	12.15/9.5	12
Volatile solids (lb)	10	8.5/8.1	10/6.64	10
Biochemical oxygen demand (BOD), 5-day (lb)	1.6	1.6/1.2	1.82/0.98	1.6
Chemical oxygen demand (COD) (lb)	11	8.9/8.5	11.17/6.97	ND
pH	7	ND	7	ND
TKN (lb)	0.45	0.45/0.36	0.45/0.34	0.43
Ammonium-N (lb)	0.079	ND	0.84/0.14	ND
Total P (lb)	0.094	0.07/0.05	0.22/0.13	0.17
Orthophosphorus (lb)	0.061	ND	0.14/ND	ND
K (lb)	0.29	0.26/0.23	0.36/0.2	0.34
Calcium (lb)	0.16	ND	0.17/0.12	ND
Magnesium (lb)	0.071	ND	0.075/ 0.05	ND
Sulfur (lb)	0.051	ND	0.052	ND
Sodium (lb)	0.052	ND	0.064	ND
Chloride (lb)	0.13	ND	0.13	ND
Iron (lb)	0.012	ND	0.012	ND
Manganese (lb)	0.0019	ND	0.0019	ND
Boron (lb)	0.00071	ND	0.00073	ND
Molybdenum (lb)	0.000074	ND	0.000075	ND
Zinc (lb)	0.0018	ND	0.0019	ND
Copper (lb)	0.00045	ND	0.00047	ND
Cadmium (lb)	0	ND	0	ND
Nickel (lb)	0.0003	ND	0.00028	ND
Total coliform bacteria (colonies)	500	ND	1.09E11 (colonies/100gm)	ND
Fecal coliform bacteria (colonies)	7.2	ND	7.45E10 (colonies/100gm)	ND
Fecal streptococcus bacteria (colonies)	42	ND	4.77E11 (colonies/100gm)	ND

Sources: ASAE, 1999; USDA, 1996; NCSU, 1994; MWPS, 1985.
ND No data.

Lander et al. averaged values from the MWPS, USDA, and NCSU datasets for N, P, and K. In all cases, EPA compared the averaged values to ASAE's data and determined them to be comparable to the lactating cow numbers. As stated earlier in this section, the milking status of dairy cattle can affect the excreted levels of N, P, and K. Lactating cows are expected to have a higher nutrient content in their manure because they typically are fed a higher energy diet. Table 6-40 presents the nutrient values in dairy manure from Lander's analysis that were used in the estimation of compliance costs for beef feedlots and dairies.

Table 6-40. Average Nutrient Values in Fresh Dairy Manure.

Parameter	Dairy Cow (lb/day/1,000-lb animal) [a]
TKN	0.45
Total P	0.08
K	0.28

Source: Lander et al., 1998.
Lander's analysis relied on 1990 NCSU data, while the NCSU data presented in this report is from 1994.

The volatile solids content of dairy manure varies depending on the age and lactation of the cow. The volatile solids content of manure for mature dairy cattle can be calculated by using data for lactating and dry cows and is presented in USDA's AWMFH. EPA's analysis assumes the dairy herd is made up of 83 percent lactating and 17 percent dry cows at any given time. Therefore, the volatile solids content for mature dairy cows, using USDA data, was calculated as

$$(8.5 \text{ lb/day/1,000 animal} \times 83 \text{ percent}) + (8.1 \text{ lb/day/1,000 animal} \times 17 \text{ percent}) = 8.45 \text{ lb/day/1,000 animal}$$

EPA used volatile solids data from USDA's AWMFH in the nonwater quality impact analyses to estimate emissions of methane.

6.3.2.2 Composition of Stored or Managed Waste

Dairy manure is often combined with large amounts of water and collected and stored in a number of different ways (see Section 4.3.5 for a detailed discussion of dairy waste management). This wastewater, therefore, has different physical properties than fresh manure. This section presents dairy waste values for waste from milking centers, and waste managed in lagoons.

Milking Centers

Approximately 15 percent of the manure generated at a dairy is produced in the milking center, which includes the milk room, milking parlor, and holding area. Milking centers that do not practice waste flushing use about 1 to 3 gallons of fresh water per day for each cow milked.

However, dairies that use flush cleaning and automatic cow washing use as much as 30 to 50 or more gallons pre day per cow (MWPS, 1985).

Waste associated with milking centers varies among the different rooms. Milk room waste typically consists of wash water associated with cleaning pipelines and holding tanks. This waste could be disposed of via septic tank systems, but many dairies include it in their manure waste management systems. Milk parlor waste typically consists of some manure and wash water from cleaning the milking equipment. Holding area waste generally contains more manure than the milk parlor and also contains wash water from cleaning the cows, and flush water from cleaning the area. Many dairies remove solids from milking center waste prior to storing the liquid waste in a lagoon. EPA used USDA data on milking center waste characteristics in the estimation of compliance costs for beef feedlots and dairies and NWQI analyses to calculate N loss during composting. Table 6-41 presents USDA data characterizing dairy waste from milking centers.

Table 6-41. Dairy Waste Characterization—Milking Centers.

		Milking Center			
Component	**Units**	**Milk Room**	**Milk Room + Milk Parlor**	**Milk Room + Milk Parlor + Holding Area**[a]	**Milk Room + Milk Parlor + Holding Area**[b]
Volume	ft^3/d/1,000#	0.22	0.6	1.4	1.6
Moisture	%	99.72	99.4	99.7	98.5
Total Solids	% wet basis	0.28	0.6	0.3	1.5
Volatile Solids	lb/1,000 gal	12.9	35	18.3	99.96
Fixed Solids	lb/1,000 gal	10.6	15	6.7	24.99
COD	lb/1,000 gal	25.3	41.7	ND	ND
BOD	lb/1,000 gal	ND	8.37	ND	ND
N	lb/1,000 gal	0.72	1.67	1	7.5
P	lb/1,000 gal	0.58	0.83	0.23	0.83
K	lb/1,000 gal	1.5	2.5	0.57	3.33
C:N ratio	unitless	10	12	10	7

Source: USDA/NRCS, 1992.
[a] Holding area scraped and flushed - manure removed via solids separator.
[b] Holding area scraped and flushed - manure included.
ND No data.

Lagoons

Lagoons that receive a significant loading of waste (e.g., from the holding area, freestall barn, and dry lots) generally operate in an anaerobic mode. Anaerobic dairy lagoon sludge accumulates at a rate of about 0.073 ft^3/lb of total solids. This is equivalent to about 266 ft^3/year per 1,000-lbs of lactating cow, assuming that 100 percent of the waste is placed in the lagoon (USDA, 1992).

Typically, storage or treatment reduces N in dairy manure by 30 to 75 percent through volatilization with only minor decreases in K and P. Although the values of K and P are low in the supernatant, which is removed on a regular basis, a disproportionate amount of the P and K is concentrated in the bottom sludge in lagoons and storage areas (Lander, 1999). EPA used USDA data on anaerobic lagoon waste characteristics in the estimation of compliance costs for beef feedlots and dairies and NWQI analyses. Table 6-42 presents USDA and NCSU data on dairy waste managed in lagoons.

Table 6-42. Dairy Waste Characterization—Lagoons.

Component	Units	Lagoon (USDA data/NCSU data)		
		Anaerobic - Supernatant	**Anaerobic - Sludge**	**Aerobic - Supernatant**
Moisture	%	99.75/ND	90/ND	99.95/ND
Total Solids	% wet basis	0.25/0.87	10/7.2	0.05/ND
Volatile Solids	lb/1,000 gal	9.16/52.4 % dry basis	383.18/56.7 % dry basis	1.67/ND
Fixed Solids	lb/1,000 gal	11.66/ND	449.82/ND	2.5/ND
COD	lb/1,000 gal	12.5/36.69	433.16/260.6	1.25/ND
BOD	lb/1,000 gal	2.92/7.8	ND	0.29/ND
N	lb/1,000 gal	1.67/4.86	20.83/19.16	0.17/ND
NH4-N	lb/1,000 gal	1.0/ND	4.17/ND	0.1/ND
P	lb/1,000 gal	0.48/2.76	9.16/41.8	0.08/ND
K	lb/1,000 gal	4.17/6.5	12.5/9.2	ND
C:N ratio	unitless	3/ND	10/ND	ND
Copper	lb/1,000 gal	ND/0.009	ND/0.46	ND
Zinc	lb/1,000 gal	ND/0.051	ND/0.74	ND

Sources: USDA NRCS 1992; NCSU, 1994.
ND No data.

6.3.2.3 Composition of Aged Manure/Waste

Dairy manure characteristics after excretion vary from operation to operation, and within the same operation during the year. Manure undergoes many changes after excretion including moisture change (dilution or consolidation), volatilization, oxidation, and reduction. These changes always affect the fresh manure characteristics. For example, it is estimated that as much as 50 to 60 percent of N in the urine portion of the manure can be lost during the first hours after excretion if some measure is not taken to preserve it (Lander, 1999). Phosphorus and potassium losses during storage are considered negligible except in open lots or lagoons. In open lots, about 20 to 40 percent of P and 30 to 50 percent of K can be lost by runoff and leaching. Up to 80 percent of the P in lagoons can accumulate in bottom sludges (USDA, 1998).

Characteristics of stored manure are either altered over time or conserved (mass). Nitrogen, for example, volatilizes as ammonia and is lost from the system. On the other hand, most of the compounds in manure (e.g., P, metals) remain in the manure over time and are considered to be conserved. Treating the manure often reduces the concentration of nonconservated elements, such as N and the organic compounds, thus reducing oxygen demands in further treatment (Lander, 1999).

Table 6-43 presents NCSU data on scraped dairy manure from a paved surface. NCSU data are used by EPA in the beef and dairy NWQI analyses.

Table 6-43. Dairy Manure Characteristics Per 1,000 Pounds Live Weight Per Day From Scraped Paved Surface.

Parameter	Unit	Value
Total solids	lb	13.7
Volatile solids	lb	11.5
TKN	lb	0.32
Ammonium-N	lb	0.077
Total P	lb	0.097
K	lb	0.22

6.4 Beef and Heifer Waste

This section describes the characteristics of beef and heifer manure and waste. In this section, manure refers to the combination of feces and urine, and waste refers to manure plus other material such as hair, soil, and spilled feed. Due to the nature of beef feedlots and heifer operations, however, even fresh manure may also contain small amounts of hair, soil, and feed.

6.4.1 Quantity of Manure Generated

Numerous analyses have estimated average manure quantities from beef cattle. Four major data sources that contain mean values for beef manure characteristics are identified below:

- American Society of Agricultural Engineers (ASAE) Standard D384.1: *Manure Production and Characteristics*, 1999. This data source contains national fresh (as-excreted) manure characteristic values by animal type (e.g., dairy, beef, veal, swine).
- USDA, *Agricultural Waste Management Field Handbook*, Chapter 4, 1996. This data source contains national manure characteristic values for fresh and managed manure (e.g., lagoon supernatant, feedlot runoff) by animal type including subtypes such as beef and heifer.

- North Carolina State University (NCSU), *Livestock Manure Production and Characterization in North Carolina*, 1994. This data source contains regional manure characteristic values for fresh and managed manure by animal type including subtypes.
- Midwest Plan Service-18 (MWPS): *Livestock Waste Facilities Handbook*, 1985. This data source contains national fresh manure characteristic values by animal type and animal weight.An analysis conducted by Charles Lander et al. of the USDA NRCS used a composite of three of these data sources (Lander et al., 1998). Lander removed ASAE data before averaging to prevent double counting of the ASAE information that is included in the MWPS data. Table 6-44 presents the fresh manure estimates from these five data sources for beef and heifer cattle.

Table 6-44. Weight of Beef and Heifer Manure.

Data Source	Quantity of Manure (wet basis) (lb/day/1,000-lb animal)		
	Steer, Bulls, and Calves	Beef Cows	Heifer
ASAE Standard	58	ND	ND
USDA *AWMFH*	55	63	82
NCSU *Livestock Manure Production and Characterization in North Carolina*	59	ND	68.4
MWPS *Livestock Waste Facilities Handbook*	60	63	ND
USDA Lander analysis	58	63	66

ND No data.

6.4.2 Waste Constituents and Concentrations

The composition and concentrations of beef and heifer waste varies from the time that it is excreted to the time it is ultimately used as a fertilizer or soil amendment. Nutrients and metals are expected to be present in beef and heifer waste due to the constituents of the feed.

6.4.2.1 Composition of "As-Excreted" Manure

Manure characteristics for beef and heifer cattle are highly variable and greatly influenced by the diet and age of the animals. Differences in weather, season, degree of confinement, waste collection systems, and overall management procedures used by feedlots across the nation add to the variability of manure characteristics in feedlots. The largest variable in fresh manure is moisture content, which significantly decreases over time. Another major variable is the ash content, which depends on the amount of soil entrained in the manure. Ash content also depends on the degree to which the manure has been degraded, which is a function of time since deposition, moisture conditions, temperature, and oxygen saturation (Sweeten et al., 1997). Ash content for fresh manure has been reported as 15.3 percent dry basis (Sweeten et al., 1995), while ash content for aged feedyard waste has been reported as high as 66 percent dry basis (TAES, 1996).

The N content of manure can begin to decrease rapidly after excretion. The urea-N part of the fecal protein rapidly converts to ammonia. Some measurements of ammonia concentrations in air around feedyards have indicated that about half of the N deposited in urine, or about one-fourth of the total N deposition of the feedlot surface, is lost to the atmosphere as ammonia gas (NH_3). The rate of ammonia emissions depends on temperature, pH, humidity, and moisture conditions, and has been found to nearly triple as manure dries after rainfall (Sweeten et al., 1997).

Table 6-45 presents data for 13 metals and nutrients found in fresh beef cattle manure, and Table 6-46 presents data on the constituents found in fresh heifer cattle manure. nitrogen is present in manure in four forms: ammonium-N, nitrate-N, nitrite-N, and organic-N. The total N is the sum of these four components, while the TKN is the sum of the organic-N and ammonium-N. phosphorus is present in manure in inorganic and organic forms and is presented as total P. Colonies of the pathogens coliform and streptococcus bacteria have also been identified in beef and heifer manure.

Table 6-45. Fresh Beef Manure Characteristics Per 1,000 Lbs. Live Weight Per Day.

Parameter	Mean (Beef)			
	ASAE	USDA	NCSU	MWPS
Moisture (%)	88.4	88.4	ND	88.4
Total solids (lb)	8.5	6.34	8.9	8.5
Volatile solids (lb)	7.2	5.74	7.3	7.2
BOD (5-day) (lb)	1.6	1.36	1.7	1.6
COD (lb)	7.8	5.86	7.9	ND
pH (lb)	7.0	ND	7.0	ND
TKN (lb)	0.34	0.30	0.36	0.34
Ammonium-N (lb)	0.086	ND	0.12	ND
Total P (lb)	0.092	0.10	0.22	0.25
Orthophosphorus (lb)	0.030	ND	0.07	ND
K (lb)	0.21	0.22	0.26	0.30
Calcium (lb)	0.41	ND	0.13	ND
Magnesium (lb)	0.049	ND	0.05	ND
Sulfur (lb)	0.045	ND	0.046	ND
Sodium (lb)	0.0030	ND	0.032	ND
Iron (lb)	0.0078	ND	0.0087	ND
Manganese (lb)	0.0012	ND	0.0012	ND
Boron (lb)	0.00088	ND	0.00095	ND
Molybdenum (lb)	0.000042	ND	0.000044	ND
Zinc (lb)	0.0011	ND	0.0010	ND
Copper (lb)	0.00031	ND	0.00033	ND
Total coliform bacteria (colonies)	29	ND	3E11 (colonies/100gm)	ND
Fecal coliform bacteria (colonies)	13	ND	1.3E11 (colonies/100gm)	ND
Fecal streptococcus bacteria (colonies)	14	ND	1.49E11 (colonies/100gm)	ND

Sources: ASAE, 1999; USDA, 1996; NCSU, 1994; MWPS, 1985
ND No data.

Table 6-46. Fresh Heifer Manure Characteristics Per 1,000 Lbs. Live Weight Per Day.

Parameter	Mean (Heifer)	
	USDA	NCSU
Moisture (%)	89.3	ND
Total solids (lb)	9.14	7.35
Volatile solids (lb)	7.77	5.34
BOD, 5-day (lb)	1.3	0.89
COD (lb)	8.3	5.67
TKN (lb)	0.31	0.23
Ammonium-N (lb)	ND	ND
Total P (lb)	0.04	0.38
Orthophosphorus (lb)	ND	ND
K (lb)	0.24	0.2
Calcium (lb)	ND	ND
Magnesium (lb)	ND	ND

Sources: USDA, 1996; NCSU, 1994.
ND No data.

EPA used beef waste characteristic data from USDA in the NWQI analyses. Lander et al. averaged values from the MWPS, USDA, and NCSU datasets for N, P, and K. EPA used Lander data in the estimation of compliance costs for beef feedlots and dairies. Table 6-47 presents Lander's averaged values for beef manure. EPA used USDA data in the estimation of compliance costs for heifer operations.

Table 6-47. Average Nutrient Values in Fresh (As-Excreted) Beef Manure.

Parameter	Beef (lb/day/1,000-lb animal)[a]
TKN	0.32
Ammonia	ND
Total P	0.098
K	0.23

Source: Lander et al., 1998.
[a] Lander's analysis relied upon 1990 NCSU data, while the NCSU data presented in this report is from 1994.
ND No Data.

6.4.2.2 Composition of Beef and Heifer Feedlot Waste

The characteristics of beef and heifer feedlot wastes vary widely because of differences in climate, rainfall, diet, feedlot surface, animal density, and cleaning frequency. Wasted feed and soil in unpaved feedlots is readily mixed with the manure because of animal movement and cleaning operations (Arrington et al., 1981). Therefore, due to the incorporation of more solids and exposure to the elements, the moisture content of beef feedlot waste is significantly lower than for fresh beef manure.

Table 6-48 presents characteristics of beef waste collected from unpaved and paved feedlots (USDA, 1992). Most feedlots are unpaved. However, for paved lots, concrete is the most common paving material, although other materials (e.g., fly ash) have been used (Suszkiw, 1999). EPA used this USDA data in the NWQI analyses to calculate N losses during composting. Table 6-49 presents NCSU data on scraped beef manure from an unpaved surface.

Table 6-48. Beef Waste Characterization—Feedlot Waste.

Component	Units	Unpaved Lot[a]	Paved Lot[b]	
			High-Forage Diet	High-Energy Diet
Weight	lb/d/1000lb	17.5	11.7	5.3
Moisture	%	45	53.3	52.1
Total Solids	% wet basis	55	46.7	47.9
Total Solids	lb/d/1000lb	9.6	5.5	2.5
Volatile Solids	lb/d/1000lb	4.8	3.85	1.75
Fixed Solids	lb/d/1000lb	4.8	1.65	0.76
N	lb/d/1000lb	0.21	ND	ND
P	lb/d/1000lb	0.14	ND	ND
K	lb/d/1000lb	0.03	ND	ND
C:N ratio	unitless	13	ND	ND

Source: USDA NRCS, 1992.
[a] Dry climate (annual rainfall less than 15 inches); annual manure removal.
[b] Dry climate; semiannual manure removal.
ND No data.

Table 6-49. Beef Manure Characteristics Per 1,000 Lbs. Live Weight Per Day From Scraped Unpaved Surface.

Parameter	Unit	Value
Total solids	lb	9.4
Volatile solids	lb	5.3
TKN	lb	0.20
Ammonium-N	lb	0.38
Total P	lb	0.062
K	lb	0.14

Source: NCSU, 1994.

Sweeten, et al., compiled and compared feedlot waste data representing “as-collected” waste, composted waste, and stockpiled waste from one area of the country (Sweeten et al., 1997). The Sweeten report was used in the estimation of compliance costs for beef feedlots and dairies and the NWQI report for calculations using the moisture content of manure. The agency also used the report’s levels of annual costs, volatile solids, and N content of composting to determine emissions for the nonwater quality impact analysis.

6.4.2.3 Composition of Aged Manure

Beef cattle feedlots typically scrape and remove the manure that is deposited on the ground about every 120 to 365 days, as opposed to dairies that scrape or remove manure as often as every day. During this “aging” process, nutrients are lost due to ammonia volatilization, runoff, and leaching. Mathers et al. determined average nutrient concentrations in aged manure ready for land application from 23 beef cattle feedlots in the Texas High Plains (Mathers et al., 1972). Since EPA has not identified national data on aged manure characteristics, these local data are presented in Table 6-50 to demonstrate the significant difference in characteristics of fresh and aged manure.

These data show that the aged beef manure N concentration is 40.3 percent of the fresh manure concentration, while P and K in aged manure are 50.9 percent and 64.5 percent, respectively, of their concentrations in fresh manure. N losses as high as 50 percent have been reported in aged beef manure due to temperature, moisture, pH, and C:N ratio. Phosphorus and K losses are primarily due to runoff but may also occur because of leaching.

Table 6-50. Percentage of Nutrients in Fresh and Aged Beef Cattle Manure.

Parameter	Unit	Fresh Manure	Aged Manure
Moisture	%	88	34
N	% dry basis	5.08	2.05
P	% dry basis	1.59	0.81
K	% dry basis	3.55	2.29

Source: Mathers et al. 1972.

6.4.2.4 Composition of Runoff from Beef and Heifer Feedlots

As with feedlot wastes, constituent characteristics of beef and heifer feedlot runoff also vary across the country. The factors that are responsible for runoff waste variations are similar to those for feedlot wastes (i.e., climate, rainfall, diet, feedlot surface, animal density, and cleaning frequency). Paved feedlots produce more runoff than unpaved lots, and areas of high rainfall and low evaporation produce more runoff than arid areas.

Numerous analyses characterizing the runoff from beef feedlots have been conducted on a local level. However, manure characteristics data collected at a local level may not be representative of the beef industry as a whole. Since the constituent concentration of feedlot runoff varies among different areas of the country, this report presents only nationally available manure characteristics and regional estimates of feedlot runoff characteristics.

The USDA *AWMFH* characterizes both the supernatant and sludge from beef feedlot runoff lagoons. EPA used these data in the estimation of compliance costs for beef feedlots and dairies, and NWQI analyses. Table 6-51 presents these waste characteristics.

Table 6-51. Beef Waste Characterization—Feedlot Runoff Lagoon.

Component	Units	Runoff Lagoon	
		Supernatant	**Sludge**
Moisture	%	99.7	82.8
Total Solids	% wet basis	0.3	17.2
Volatile Solids	lb/1,000 gal	7.5	644.83
Fixed Solids	lb/1,000 gal	17.5	788.12
COD	lb/1,000 gal	11.67	644.83
N	lb/1,000 gal	1.67	51.66
NH_4-N	lb/1,000 gal	1.5	ND
P	lb/1,000 gal	ND	17.5
K	lb/1,000 gal	7.5	14.17
Copper	lb/lb	ND	1.94×10^{-4}
Zinc	lb/lb	ND	9.29×10^{-4}

Source: USDA NRCS, 1992; NCSU, 1994.
ND No data.

6.5 Veal Waste

This section describes the characteristics of veal manure and waste. In this section, manure refers to the combination of feces and urine, and waste refers to manure plus other material such as hair, soil, and spilled feed. Due to the nature of veal operations, however, even fresh manure may also contain small amounts of hair and feed.

This section discusses the following:

- Section 6.5.1: Quantity of manure generated; and
- Section 6.5.2: Waste constituents and concentrations.

6.5.1 Quantity of Manure Generated

National data on veal waste characteristics are available from the following three data sources:

- ASAE Standard D384.1: *Manure Production and Characteristics*, 1999. This data source contains national fresh manure characteristic values by animal type (e.g., dairy, beef, veal, swine).
- USDA, *AWMFH*, Chapter 4, 1996. This data source contains national manure characteristic values for fresh and managed manure (e.g., lagoon supernatant, feedlot runoff) by animal type including subtypes such as veal.
- NCSU, *Livestock Manure Production and Characterization in North Carolina*, 1994. This data source contains regional manure characteristic values for fresh and managed manure by animal type including subtypes.

Table 6-52 presents the average fresh manure characteristics for veal from these three data sources. EPA used USDA data in the estimation of compliance costs for veal operations.

Table 6-52. Average Weight of Fresh Veal Manure.

Data Source	Quantity of Manure (wet basis) (lb/day/1,000 lb animal)
ASAE Standard	62
USDA *AWMFA*	60
NCSU, *Livestock Manure Production and Characterization in North Carolina*	61.76

6.5.2 Waste Constituents and Concentrations

The composition and concentrations of veal waste vary from the time that it is excreted to the time it is ultimately used as a fertilizer or soil amendment. Nutrients and metals are expected to be present in veal waste due to the constituents of the feed. This section discusses the composition of fresh manure.

Table 6-53 presents data for nine metals and nutrients found in fresh veal manure. Veal manure is very fluid, with the consistency of a sloppy mortar mix, and is often diluted by large volumes of wash water (Meyer, 1987). The moisture content of fresh veal manure is approximately 98 percent (USDA, 1992).

Veal manure is typically stored in tanks, basins, and pits until it is pumped out onto the land as fertilizer. However, most of the fertilizer value of veal manure remains in the solids in a settling tank (Meyer, 1987). Over time, the most significant compositional change in veal manure, stored in pits, is the conversion of organic-N in fresh manure to ammonium-N and loss of total N to the atmosphere in the form of ammonia. Much of the high ammonia loss is due to microbial degradation of the organic matter including total N components (Sutton et al., 1989). EPA used USDA data in the estimating compliance costs and NWQI analyses for veal operations.

Table 6-53. Fresh Veal Manure Characteristics Per 1,000 Lbs. Live Weight Per Day.

Parameter	Unit	Mean (Veal)		
		ASAE	USDA	NCSU
Moisture	%	97.5	97.5	ND
Weight	lb	62	60	61.8
Total solids	lb	5.2	1.5	4.0
Volatile solids	lb	2.3	0.85	2.1
BOD (5-day)	lb	1.7	0.37	0.83
COD	lb	5.3	1.5	1.5
pH	lb	8.1	ND	7.7
TKN	lb	0.27	0.20	0.24
Ammonium-N	lb	0.12	ND	0.11
Total P	lb	0.066	0.03	0.053
K	lb	0.28	0.25	0.27
Calcium	lb	0.059	ND	0.059
Magnesium	lb	0.033	ND	0.33
Sodium	lb	0.086	ND	0.16
Iron	lb	0.00033	ND	0.00033
Zinc	lb	0.013	ND	0.013
Copper	lb	0.000048	ND	0.000048

Source: ASAE, 1999; USDA, 1996; NCSD, 1994.
ND No data.

6.6 <u>Horse Waste</u>

The horse industry raises animals for diverse uses, including pleasure, showing, breeding, racing, farm/ranch, and other minor uses. Because the horse industry is so diverse and much of the population is off farm, statistics on horse production are less available than other livestock.

6.6.1 Quantity of Manure Generated

An average 1,000-pound horse generates approximately 9 tons of manure a year (51 pounds per day). The volume of this solid excrement ranges from 0.75 to 1.0 cubic foot per day. Urine production ranges from 2.25 to 8 gallons per day depending upon diet, activity, and environmental conditions (Wheeler and Cirelli, 1995). Depending on practices, substantial amounts of bedding are added to the wastes.

6.6.2 Horse Waste Characteristics

The characteristics of horse waste will vary by the type of diet fed to the animal, which can range from low-nutrient crops such as Bermuda grass to N-rich forages such as clover, in addition to supplemental feeding. Since horses, unlike ruminants, are limited in their ability to use forages of low nutritive value, feeding regimes require a greater level of management, especially for horses raised primarily in pastures.

6.7 References

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CHAPTER 7

POLLUTANTS OF INTEREST

7.0 INTRODUCTION

Pollution generated at feedlot operations can arise from multiple sources. These sources, including animal waste, process wash waters, litter, animal carcasses, spills of pesticides, and pharmaceuticals, are the primary sources of potential environmental contamination.

Excreted animal waste contains undigested and partially digested feed, partially metabolized organic material, dead and living microorganisms from the digestive tract, cell wall material and other organic debris from the digestive tract, and excess digestive juices. Additional microorganisms may grow in the waste after it has been excreted. Depending on the type of feed provided to the animals and whether feed additives have been used, animal wastes can also contain pharmaceuticals (antibiotics and hormones), and trace inorganic elements.

Animal carcasses, which may contain pathogens, nutrients, and chemical toxicants, can pose an environmental problem, especially in the poultry industry where many operations have historically used burial as a means for disposal. For example, during 1990, several state agencies in Arkansas tested the management of dead-bird disposal pits and found high soil concentrations of ammonium (USEPA, 1999). Improper disposal of poultry carcasses has been implicated in ground water contamination; however, in recent years, greater regulation of animal disposal has reduced the risk of environmental contamination from buried animal carcasses. Arkansas, for example, has outlawed the use of dead-bird disposal pits. Other states have also issued guidelines or regulations for disposal of animal carcasses and require operators to use specific practices such as composting.

In the preliminary study on environmental impacts from animal feedlot operations, EPA (1998) identified and described the major animal waste constituents that can adversely affect the environment. Additional information on potential impacts can be found in the *Environmental Assessment of Proposed Revisions to the National Pollutant Discharge Elimination System Regulation and Effluent Limitations Guidelines for Concentrated Animal Feeding Operations* (USEPA, 2000). As demonstrated in Chapter 6, the physical and chemical characteristics of manure differ between animal sectors as well as within animal sectors. The following pollutants of interest identified by EPA in its preliminary feedlots study are described below:

- Nutrients (nitrogen, phosphorus)
- Total suspended solids (including sediment)
- Biochemical oxygen demand (BOD)

- Pathogen
- Chemical oxygen demand (COD)
- Other contaminants including salts, trace elements, and pharmaceuticals

Exposure pathways of contaminants in soil include direct ingestion, inhalation of dusts, ingestion of ground or surface water contaminated from migration of chemicals through soil or runoff from soil, dermal absorption, and ingestion of produce that has been contaminated through plant uptake (USEPA, 1996). Constituents in manure will have an impact on water quality if significant amounts reach surface or ground water. Management practices can reduce or block the potential transport of these constituents. Movement of constituents in manure is driven primarily by precipitation events, runoff and erosion of soluble and particulate components, leaching to ground water of soluble compounds, and wind erosion of dry material (USEPA, 2000).

7.1 Conventional Waste Pollutants

Biochemical Oxygen Demand

BOD is a measure of the oxygen-consuming requirements of organic matter decomposition. When animal waste is discharged to surface water, it is decomposed by aquatic bacteria and other microorganisms. Decomposing organic matter consumes oxygen and reduces the amount available for aquatic animals. Severe reductions in dissolved oxygen levels can lead to fish kills. Even moderate decreases in oxygen levels can adversely affect waterbodies through decreases in biodiversity as manifested by the loss of fish and other aquatic animal populations.

Total Suspended Solids

Suspended solids can clog fish gills and increase turbidity. Increased turbidity reduces penetration of light through the water column, thereby limiting the growth of desirable aquatic plants that serve as a critical habitat for fish, shellfish, and other aquatic organisms. Solids that settle out as bottom deposits can alter or destroy habitat for fish and benthic organisms. Solids also provide a medium for the accumulation, transport, and storage of other pollutants including nutrients, pathogens, and trace elements. Sediment-bound pollutants often have an extended interaction with the water column through cycles of deposition, resuspension, and redeposition.

Fecal Coliform Bacteria

Manure contains diverse microbial populations. Included are members of the normal gastrointestinal tract flora, such as members of the fecal coliform and fecal streptococcus groups of bacteria. These are the groups of bacteria commonly used as indicators of fecal contamination and the possible presence of pathogenic species. A discussion of pathogens found in the waste of AFOs is given in section 7.2.

7.2 Nonconventional Pollutants

Nutrients (Nitrogen, Phosphorus)

Because of its nutrient content, animal manure can serve as a valuable agricultural resource. In an area where the amount of nutrients in manure generated from AFOs is greater than the nutrient requirements of the crops grown in the area, excess land application has occurred, which can lead to increased nutrient runoff and seepage and subsequent degradation of water resources.

As noted in Chapter 6, wastes contain significant quantities of nutrients, particularly nitrogen (N) and phosphorus (P). Manure N occurs primarily in the form of organic-N and ammonia-N compounds. In its organic form, N is unavailable to plants. However, through bacterial decomposition, organic-N is transformed into ammonia, which is oxidized (by nitrification) to nitrite and ultimately to nitrate. Ammonia and nitrate are bioavailable and therefore have fertilizer value. These forms can also produce adverse environmental impacts when they are transported in excess quantities to the environment.

Ammonia. "Ammonia-N" includes the ionized form (ammonium) and the un-ionized form (ammonia). Ammonium is produced when microorganisms break down organic-N products in manure, such as urea and proteins. This decomposition can occur under aerobic or anaerobic conditions. Both forms are toxic to aquatic life, although the un-ionized form (ammonia) is much more toxic.

Ammonia is of environmental concern because it exerts a direct BOD on the receiving water. Ammonia can lead to eutrophication, or nutrient overenrichment, of surface waters. Ammonia itself is a nutrient and is also easily transformed to nitrate (another nutrient form of N) in the presence of oxygen. Although nutrients are necessary for a healthy ecosystem, the overabundance of nutrients (particularly N and P) can lead to nuisance algae blooms.

Nitrate. Nitrite is toxic to most fish and other aquatic species, but it usually does not accumulate in the environment because of its rapid conversion to nitrate in an aerobic environment. Nitrate is a valuable fertilizer because it is biologically available to plants. Excessive levels of nitrate in drinking water, however, can produce adverse human health and environmental impacts. For example, human infants exposed to high levels of nitrate can develop methemoglobinemia, commonly referred to as "blue baby syndrome" because the lack of oxygen can cause the skin to appear bluish in color. To protect human health, EPA has set a drinking water maximum contaminant level (MCL) of 10 mg/L for nitrate-N. N is the primary contributor to eutrophication in brackish and saline waters (USEPA, 2000).

N is interchanged among the atmosphere and organic matter and inorganic compounds in soil or water through the N cycle. The biological transformations of N that make up this process include N fixation, nitrate reduction, and denitification. Atmospheric nitrogen (N_2) can be bound by microorganisms with carbohydrates, water, and hydrogen to form ammonium and carbon dioxide in the process of N fixation. Aquatic microorganisms with the ability to fix atmospheric nitrogen include photosynthetic bacteria, *Azotobacter*, and some species of *Clostridium*. In soil, *Rhizobium* can fix atmospheric nitrogen in the root nodules of leguminous plants. Ammonium can be further converted by *Nitromonas* and *Nitrobacter* bacteria into nitrite and nitrate, respectively, in the process of nitrate reduction. This process provides most plants with the form of N they are able to absorb (nitrate). Ammonium present in animal manure can also be converted into nitrate by these bacteria for use by plants. Denitrification is the process by which fixed N present in soil or water is returned to the atmosphere by bacteria in the form of N_2, allowing the N cycle to begin again (Manahan, 1991).

Phosphorus. Animal wastes contain both organic and inorganic forms of P. P occurs almost exclusively in the form of inorganic and organic phosphates in natural waters. Organic phosphate is phosphate associated with a carbon-based molecule such as plant or animal tissue. Phosphate not associated with organic matter is inorganic, which is the form required for uptake by plants. Animals can use organic or inorganic phosphate. Both organic and inorganic forms can be dissolved in water or suspended (attached to particles in the water column). Sources of P include soil and rocks, wastewater treatment plants, runoff from fertilized lawns and cropland, failing septic systems, runoff from animal manure storage areas, disturbed land areas, drained wetlands, water treatment, and commercial cleaning preparations (USEPA, 2002a). The majority of P binds to mineral and organic particles in manure and is subject to runoff and erosion more than leaching except in very sandy soils with low P-binding capacity (USEPA, 2000).

P is of concern in surface waters because it is a nutrient that can lead to eutrophication and the resulting adverse impacts—fish kills, reduced biodiversity, objectionable tastes and odors, increased drinking water treatment costs, and growth of toxic organisms. At concentrations greater than 1.0 mg/L, P can interfere with coagulation in drinking water treatment plants (Bartenhagen et al., 1994).

P is of particular concern in fresh waters, where plant growth is typically limited by phosphorous levels. Under high pollutant loads, however, fresh water may become nitrogen-limited (Bartenhagen et al., 1994). Thus, both N and P loads may contribute to eutrophication.

P is interchanged in an aquatic ecosystem through the P cycle. Inorganic P from various natural and human sources is taken up by plants and converted to organic P. Animals graze on plants and thereby take up organic P. Organic P is released to the ecosystem in animal feces and in decaying animals and plants, generally to the bottom of the lake or stream. Bacterial decomposition converts organic P into inorganic P in both dissolved and suspended forms. Inorganic P is returned to the water column, allowing the P cycle to begin again, when the bottom of the waterbody is disturbed by animals, human activity, chemical interactions, or water currents. In streams, P tends to move downstream over time because the current carries decomposing plant and animal material and dissolved P downstream. P is stationary in waterbodies only when taken it is taken up by plants or bound to particles that settle to the bottom of pools (USEPA, 2002a).

Chemical Oxygen Demand

COD is another measure of oxygen-consuming pollutants in water. The COD test differs from the BOD test in that it measures the amount of oxygen required to oxidize all organic matter present in a sample regardless of how biologically assimilable the organic matter is because it uses a strong chemical oxidizing agent instead of microorganisms to oxidize the organic compounds in a sample (Masters, 1997). BOD only measures the oxygen required to oxidize biologically degradable material present in a sample. The COD test is used to measure oxygen-consuming pollutants in water because all organic compounds, with few exceptions, can be oxidized by the action of strong oxidizing agents under acidic conditions. The measured value of COD is generally greater than BOD in a sample, although these values are similar in samples containing easily biodegradable material. Because the COD test can be performed more quickly than the BOD test, it is sometimes used to estimate BOD.

Pathogens

Manure contains diverse microbial populations. There are many examples that demonstrate that pathogens from manure can be a problem. Other studies show that manured fields do not pose a significant threat to surface waters. Most pathogens present in animal manure are from the gastrointestinal tract and can be divided into those pathogens that are highly host-adapted and not considered to be pathogenic to humans and those that are capable of causing infection in humans (zoonoses). For example, most *Salmonellae* are zoonoses, but *S. pulloram* and *S. gallinarum*, which might be present in poultry manures, are not. However, each of these species may be included in gross estimates of *Salmonella* densities. The pathogens that might be present in poultry and swine manures can also be divided into those microorganisms which are commonly present and those which are less common. For example in poultry manures, *Campylobacter jejuni* is commonly present while *Mycobacterium avium* is less common. These distinctions are important in assessing the potential public health risks associated with poultry and swine operations, as well as other animal feeding operations.

The interactions between pathogens, cattle, and the environment are not well understood but current literature suggests that dairy and beef cattle shed pathogens that are known to be infectious to humans. The threat posed by pathogens in animal manure is influenced by the source, pH, dry matter, microbial, and chemical content of the feces. Solid manure that is mixed with bedding material is more likely to undergo aerobic fermentation in which temperature increases reduce the number of viable pathogens. However, some pathogens grow under a wide range of conditions that makes their control very difficult. Quantifying the risk associated with these pathogens is thus challenging. Rapidly changing pathogen numbers, changes in the infective status of the host, and survivability of the pathogens all make it increasingly difficult to determine how much of a threat animal-excreted pathogens are to society. Moreover, methods of pathogen detection produce varying results, making it difficult to compare studies that use different analyses (Pell, 1997).

The most common pathogens and found in animal manures and capable of causing disease in humans are *Salmonella*, *Escherichia coli*, *Bacillus anthracis, Mycrobacterium paratuberculosis*, *Brucella abortus, Leptospira* spp., *Chlamydia* spp., *Rickettsia* spp., and *Listeria monocytogenes* (Epstein, 1998). In addition, *Cryptosporidium parvum* oocysts (the eggs of a protozoan parasite that can cause gastrointestinal illness in humans) found in calf and pig manure (USDA, 1996) and *Giardia* oocysts in young dairy cattle manure (Pell, 1997) appear to be infectious to humans.

Unlike biosolids, the bacterial content of animal manure is currently not regulated; however, the Federal Part 257 regulation does include provisions regarding general management of these materials to help ensure that practices will not impact threatened or endangered species or habitat be either a direct discharge or a nonpoint source of pollutants or contaminate underground drinking water sources (USEPA, 2000). Fecal coliform, fecal streptococci, *Escherichia coli*, and enterococci are commonly used indicators of human and animal fecal contamination. These bacteria are not harmful in themselves but they indicate the possible presence of pathogenic bacteria, viruses, and protozoa that live in human and animal digestive systems. Because it is difficult to test for the pathogens themselves, tests for indicator bacteria are used instead (USEPA, 2002b).

EPA now recommends that enterococci and *Escherichia coli* be used as indicators of fecal contamination in fresh water and enterococci be used as an indicator of fecal contamination in salt water; however, several states continue to use fecal coliform as their indicator water quality standard (USEPA, 2002b). Indicator bacteria can be used to determine whether surface waters have been contaminated from manure applied to nearby fields. In the past, fecal streptococci and fecal coliform were monitored together and a ratio of fecal coliform to streptococci was calculated to determine whether the contamination was of human or nonhuman origin; however, this ratio is no longer recommended by EPA (USEPA, 2002b).

The levels of fecal coliform and fecal streptococci bacteria have been measured in the manure of several livestock animal types. Fecal coliform bacterial densities were measured in units of colonies/1,000 kg live animal mass per day at densities of 45 ± 27 for sheep; 18 ± 12 for swine; 7.5 ± 2.0 for layer chickens; and 16 ± 28 for dairy cows. Fecal streptococci bacterial densities were measured in units of colonies/1,000 kg live animal mass per day at densities of 62 ± 73 for sheep; 530 ± 290 for swine; 16 ± 7.2 for layer chickens; and 92 ± 140 for dairy cows (ASAE, 1999).

For additional information on pathogens see the *Environmental and Economic Benefit Analysis* and the *Environmental Assessment*.

Other Potential Contaminants

Animal wastes can contain other chemical constituents that could adversely affect the environment. These constituents include salts trace elements and pharmaceuticals, including antibiotics. Although salts are usually present in waste regardless of animal or feed type, trace elements and pharmaceuticals are typically the result of feed additives to help prevent disease or promote growth. Accordingly, concentrations of these constituents will vary with operation type and from facility to facility.

Salts and trace elements. Animal manure contains dissolved mineral salts. The major cations contributing to salinity are sodium, calcium, magnesium, and potassium; the major anions are chloride, sulfate, bicarbonate, carbonate, and nitrate. In land-applied wastes, salinity is a concern because salts can accumulate in the soil and become toxic to plants; they can also deteriorate soil quality by reducing permeability and contributing to poor tilth. Direct discharges and salt runoff to fresh surface waters contribute to salinization and can disrupt the balance of the ecosystem. Leaching salts can deteriorate ground water quality, making it unsuitable for human consumption. Trace elements such as arsenic, copper, selenium, and zinc are often added to animal feed as growth stimulants or biocides (Sims, 1995). When applied to land, these elements can accumulate in soils and become toxic to plants, and can affect human and ecological health.

Metals in potentially toxic concentrations in poultry, swine, and cow manures include arsenic, cadmium, copper, lead, molybdenum, nickel, selenium, and zinc (Overcash, et al., 1983). In promulgating standards for the disposal of sewage sludges by land application, EPA has established maximum allowable concentrations and cumulative loading limits for each of these metals as well as beryllium and mercury (Federal Register, 1989). It has generally been assumed that the metal concentrations in manure are well below those allowable for land application of wastewater treatment sludge; however, metal loadings may accumulate in cropland to which manure has been applied for many years.

Selenium and arsenic (as arsinilic acid) supplementation of complete feeds for poultry and swine is directly limited by EPA to 0.3 ppm and 90 ton of feed, respectively (21 CFR 573.920; 21 CFR 558.62). Copper and zinc are fed to swine as growth stimulants at levels significantly above nutritional requirements (Dritz et al., 1997). Arsenic is fed as a growth stimulant to broiler chickens. Drugs administered either prophylactically or therapeutically can also contain metals. Also, concentrated sources of macrominerals such as calcium might contain metals such as copper, manganese, and zinc, as well as other metals with no biological value. Copper and zinc in freshly excreted poultry and swine waste has been measured at concentrations between 12 and 15 mg/kg of total solids and between 42 and 310 mg/kg of total solids, respectively (Barker and Zublena, 1995).

Unlike poultry and swine, cattle are typically not fed excess amounts of metals because these metals do not have a growth-promoting effect on cattle. Zinc and copper in dry manure have been measured at concentrations of 50 mg/kg and 180 mg/kg, respectively in dairy cattle, and 25 mg/kg and 110 mg/kg, respectively in beef cattle. The differences in manure concentrations most likely occurred because enriched mineral supplements were supplied to the dairy cattle but not to the beef cattle (Nicholson, 1999).

Metals not essential for plant or animal nutrition are a concern because they do not degrade over time, they are relatively immobile, and they accumulate in the upper layers of the soil (Rutgers Cooperative Extension, 2000). Heavy metal concentrations in various fertilizers differ and large variabilities in concentration occur within the same fertilizer type. Researchers at Rutgers Cooperative Extension used measured metal concentrations in manure from existing studies to predict the concentrations of metals in soil after 100 years of application at rates of 6.2, 3.2, and 1.8 dry tons for dairy, poultry, and swine manure, respectively. From their model results, the researchers predicted that copper, lead, and zinc would persist in the soil.

According to a draft study performed by the Water Environment Research Foundation (WERF), farmers apply 120 million dry tons of animal manure on their farmlands annually. The draft WERF study results show that metal concentrations in swine and poultry manures are comparable to those in biosolids. The bioavailability and mobility of metals in soil is dependent on their form. Oxide-bound and organically bound metals largely remain immobile and are not absorbed by plants, while water soluble forms are more likely to be taken up by plants or to be carried off-site in runoff. The investigators for the WERF study are planning to perform more research on the metal leachability of manures, biosolids, and fertilizers (Spicer, 2002). This information will help to determine the impact of these heavy metals on humans and on the environment.

Researchers have found that aberrations and damage occurred in a high percentage of sperm cells from earthworms (*Eisenia fetida*) with elevated body burdens of heavy metals. The researchers exposed these earthworms to metals in their feed by placing them in cattle manure to which either 0.01 percent of lead or 1,000 micromoles/gram of manganese salts were added (Reinecke and Reinecke, 1997). High metal concentrations in soil may affect the ability of earthworms to reproduce and consequently affect soil fertility.

Heavy metals in soil can also adversely affect plant growth and survival and can accumulate in plants and subsequently affect the health of humans and animals who eat or use the plant products. Cadmium in soil is readily absorbed by tobacco, mushrooms, spinach, and other leafy vegetables. When tobacco is smoked, much of the cadmium is taken up by the human body. The National Research Council has recommended that the cadmium content of crops used to feed animals should be 0.5 mg/kg or less to reduce the cadmium concentration in meat (Cornell University, 1993). Symptoms of acute toxicity from ingestion of cadmium in humans include nausea, vomiting, and abdominal pain. Long-term effect of low-level exposure to cadmium are lung disease, emphysema, and kidney disease (Klaasen, 1996). Lead and arsenic are generally not absorbed by field crops; however, an accumulation of lead or arsenic in the soil may pose a risk to children and animals that might eat the soil (Klaasen, 1996). Lead exposure can adversely affect the nervous system, especially in children, which can lead to neurological, neurobehaviorial, and developmental impacts. Ingestion of large doses of arsenic (70 to 80 mg) can cause fever, anorexia, and heart arrhythmia, and can lead to death in humans. Long-term exposure to low concentrations of arsenic can cause adverse effects to the nervous system, peripheral vascular disease, and liver injury (Klaasen, 1996). Copper and zinc are toxic to plants in large concentrations (Cornell University, 1993). Ingestion by humans of copper and zinc in soil in large enough quantities to cause toxicity is unlikely.

Antibiotics and hormones. A number of pharmacologic agents are used in the production of poultry and swine, among them a variety of antibiotics and hormones. Nonantibiotic antimicrobials, such as sulfonamides, and some antibiotics, such as streptomycin, are used primarily to cure existing infections (therapeutic use). However, most of the antibiotics used in both the swine and the poultry industries are used both therapeutically and nontherapeutically as feed additives to promote growth, to improve feed conversion efficiency, and to prevent disease (Mellon et al., 2001). When antibiotics are used for nontherapeutic uses the dosage rates are substantially lower than when they are administered for therapeutic use.

Mellon and other investigators (2001) estimate that 24.6 million pounds of antibiotics are used annually by livestock producers for nontherapeutic purposes, of which approximately 10.3 million pounds are used in hog production, 10.5 million pounds are used in poultry production, and 3.7 million pounds are used in cattle production. Tetracycline, penicillin, erythromycin, and other antibiotics are commonly used for these nontherapeutic purposes (Mellon, et al., 2001). The antibiotics in manure applied to soil can persist in soil for 1 day to several weeks or longer. The rate of inactivation of these antibiotics is related to the temperature of the soil and the chemical structure of the antibiotic (Gavalchin and Katz, 1994).

Despite the fact that there is little information in the literature about concentrations of antibiotics in poultry and swine manures, it is known that the primary mechanisms of elimination are in urine and bile (Merck and Company, 1998). Approximately 25 to 75 percent of antibiotics administered to feedlot animals could be excreted in the feces (Chee-Sanford, et al., 2001). The form excreted, the unchanged antibiotic or metabolites or some combination thereof, is antibiotic specific, as is the mass distribution among mechanisms of excretion. These compounds may pose risks to humans and the environment. For example, chronic toxicity may result from low-level discharges of antibiotics. For example, chronic toxicity may result from low-level discharges of antibiotics (Merck and Company, 1998).

Use of antibiotics in agriculture might contribute to antimicrobial resistance. The main route of transmission of drug resistance is considered to be consumption of contaminated food. Drug resistance can also be transmitted through natural waters and soil. Lagoons and pit systems are commonly used for waste disposal in animal agriculture operations. Antibiotic and antibiotic-resistant microorganisms have the potential to seep from these waste lagoons into ground water (Chee-Sanford, et al., 2001). The large quantities of antibiotics entering the environment from manure and other sources allow for survival of antibiotic-resistant strains of microorganisms that can start to predominate the microbial population, which can cause certain diseases in humans and animals to be more difficult to treat than they were in the past (Mellon, et al., 2001). For example, an outbreak of salmonellosis in humans has been linked to infection by antibiotic-resistant *Salmonella newport* (Gavalchin and Katz, 1994). Antibiotics introduced in soil through manure application can also affect the bacterial populations of the soil (Gavalchin and Katz, 1994), which might lead to decreased soil fertility.

Specific hormones are used to increase productivity in the beef and dairy industries but hormones are not used in the poultry or swine industries. Thus, hormones present in poultry and swine manures are only in naturally occurring concentrations. U.S. farmers raise 36 million beef cattle per year of which two-thirds are given hormones. Some steer receive androgens to build their muscle mass and some cows receive female sex hormones to free up resources that would have otherwise been used for the reproductive cycle (Raloff, 2002).

A large portion of hormones passes through cattle in their feces. Waterborne androgen hormones have been detected in waterbodies downstream of animal feedlots. Investigators have found that male fish raised in water obtained from these waterbodies had significantly reduced testicle size in comparison to fish raised in water not containing these hormones, indicating that these waterborne hormones caused male fish to produce less testosterone and to be less fertile than male fish raised in water not containing these hormones. The investigators also suggested that these effects could have been caused by natural androgens and estrogens in manure in addition to or instead of being caused by the synthetic hormones given to the livestock (Raloff, 2002). Also, estrogen hormones in the environment have been implicated in the drastic reduction in sperm counts among men (Sharpe and Skakkebaek, 1993) and reproductive disorders in a variety of wildlife (Colburn et al., 1993).

Hormones in manure applied to soil might be degraded by soil bacteria and photochemical reactions. In addition, hormones might be leached by rain into lower soil horizons or washed directly into surface waters. Dissolved organic matter can bind steroids and enhance their solubility and mobility in the water (Schiffer, et al., 2001), increasing the potential of ground water and surface waters contamination by these compounds.

Schiffer and other investigators (2001) studied the residue and degradation of two growth promoting hormones used in cattle in the United States and Canada, trenbolone acetate and melegestrol acetate, in animal dung, liquid manure, and soil. The researchers found that trenbolone acetate concentrations were 5 to 70 times higher in solid manure than in liquid manure. Trenbolone acetate was determined to have a half-life of 267 days in liquid manure and was partially degraded in solid manure after 4.5 months of storage. The researchers found that trenbolone acetate was not detected in soil fertilized with liquid manure containing this hormone after 40 days; however, they did detect trenbolone acetate in soil 58 days after in had been fertilized with stored solid dung which contained lower concentrations of this hormone than the liquid manure. The researchers suggested that the trenbolone acetate might have adsorbed to the straw material present in the solid dung, which may have protected this hormone from leaching or degrading. The investigators also found that residues of melegestrol acetate in solid dung were more stable than trenbolone acetate because melegestrol acetate concentrations in dung did not decrease significantly after 4 months. They were able to detect melegestrol acetate in soil fertilized with solid manure from the spring until the end of cultivation (Schiffer, et al., 2001).

7.3 Priority Pollutants

The CWA requires states to adopt numeric criteria for priority toxic pollutants if EPA has published criteria guidance and if the discharge or presence of these pollutants could reasonably be expected to interfere with the designated uses of the state's waters. EPA currently lists a total of 126 toxic priority pollutants in 40 CFR 122, Appendix D. Other metal and organic chemicals, however, can cause adverse impacts.

Animal wastes may contain a variety of priority pollutants including the potentially toxic metals: arsenic, cadmium, chromium, copper, lead, molybdenum, nickel, selenium, and zinc (Overcash et al., 1983; ASAE, 1999). In promulgating standards for the disposal of sewage sludges by land application, EPA has established maximum allowable concentrations and cumulative loading limits for each of these metals. Although information about the concentrations of these metals in poultry and livestock manures, and its variability, is quite limited, it generally has been assumed that these concentrations are well below those allowable for land application of wastewater treatment sludges. However, the issue of cumulative loading has been raised periodically in light of long-term use of cropland for manure disposal, especially in areas where poultry and livestock production is concentrated (Sims, 1995).

Given the degree of vertical integration that has occurred in both the poultry and the swine industries, much of the feed manufacturing for these industries is controlled by integrators. Thus, information about the current use of trace mineral supplements in formulating both poultry and swine feeds is difficult to obtain because the integrators consider it proprietary. However, it appears to be a reasonable assumption that arsenic, copper, selenium, and zinc are typically added to poultry feeds and that copper, selenium, and zinc are common components of trace mineral premixes used in the manufacturing of swine feeds. It is probable that commonly used feed supplements also contain some manganese.

Feed amendments of selenium (0.3 part per million) and arsenic (90 grams per ton of feed) are regulated by the U.S. Food and Drug Administration (FDA) (Title 21, Part 573.920 of the Code of Federal Regulations). Levels of other trace minerals as feed supplements are regulated only indirectly by the FDA through maximum allowable concentrations in specified tissues at slaughter or in eggs.

Currently available information about metal concentrations in poultry and swine manures almost exclusively dates back to the 1960s and 1970s (Barker and Zublena, 1995). Kornegay's (1996) data are also somewhat dated, because they are averages over a 14-year period prior to 1992. When compared with Barker and Zublena's data for swine, Kornegay's data suggest that the concentrations of copper and zinc in swine manure have increased significantly over time. However, little is known about the current concentrations of trace metals in poultry and swine manures except that the variations in concentrations are substantial.

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CHAPTER 8

TREATMENT TECHNOLOGIES AND BEST MANAGEMENT PRACTICES

8.0 INTRODUCTION

This chapter provides an overview of treatment technologies and best management practices (BMPs) for pollution prevention at animal feeding operations (AFOs), as well as for the handling, storage, treatment, and land application of wastes. The discussion focuses on technologies and BMPs currently implemented at domestic AFOs, but it also describes technologies and BMPs that are under research and development, are undergoing laboratory or field testing, or are used in other countries.

Many waste management technologies and BMPs are used by more than one animal sector, and information on them is presented in a general discussion form. However, the manner in which a particular technology or BMP is used or its degree of acceptance can vary among sectors. These differences are presented by animal sector where necessary.

8.1 Pollution Prevention Practices

Pollution prevention practices can be divided into feeding strategies that reduce the concentration of pollutants in waste and practices that reduce the amount of water used in the handling of wastes. Reduced water use or handling of wastes in a dry or drier form lowers the risk of pollutants entering surface waters. Reduced water use has the added benefit of making the waste less expensive to move from the facility site.

8.1.1 Feeding Strategies

Feeding strategies designed to reduce nitrogen (N) and phosphorus (P) losses include more precise diet formulation, enhancing the digestibility of feed ingredients, genetic enhancement of cereal grains and other ingredients resulting in increased feed digestibility, and improved quality control. These strategies increase the efficiency with which the animals use the nutrients in their feed and decrease the amount of nutrients excreted in the waste. With a lower nutrient content, more manure can be applied to the land and less cost is incurred to transport excess manure from the farm. Strategies that focus on reducing P concentrations, thus reducing overapplication of P and associated runoff into surface waters, can turn manure into a more balanced fertilizer in terms of plant requirements.

Feeding strategies that reduce nutrient concentrations in waste have been developed for specific animal sectors, and those for the swine, poultry and dairy industries are presented separately in the following discussion. The application of these types of feeding strategies to the beef industry has lagged behind other livestock sectors and is not discussed here.

8.1.1.1 Swine Feeding Strategies

Practice: Precision Nutrition for Swine

Description: Current swine feed rations can result in overfeeding proteins and other nutrients to animals because they are designed to ensure that nutritional requirements are met and growth rate maintained. Precision nutrition entails formulating feed to meet more precisely the animals' nutritional requirements, causing more of the nutrients to be metabolized, thereby reducing the amount of nutrients excreted. For more precise feeding, it is imperative that both the nutritional requirements of the animal and the nutrient yield of the feed are fully understood.

When swine are fed typical diets, the P-use efficiency is on the order of 10 to 25 percent, while the N-use efficiency is on the order of 30 percent. These figures suggest that swine use these nutrients very inefficiently. An excess of N in the diet, principally from protein in feed, leads to inefficient utilization of nutrients. Phytate-phosphorus[1] (phytate-P), the most common form of P in feedstuffs (56 to 81 percent), is not well utilized by pigs because they lack intestinal phytase, the enzyme needed to remove the phosphate groups from the phytate molecule. Therefore, supplemental P is added to the diet to meet the pig's growth requirements, while phytate-P from the feed is excreted in the urine, thus increasing P concentrations in the manure. Because some feedstuffs are high in phytase, and because there is some endogenous phytase in certain small grains (wheat, rye, triticate, barley), there is wide variation in the digestibility of P in feed ingredients. For example, only 12 percent of the total P in corn is digestible whereas 50 percent of the total P in wheat is digestible. The P in dehulled soybean meal is more available than the P in cottonseed meal (23 versus 1 percent), but neither source of P is as highly digestible as the P in meat and bone meal (66 percent), fish meal (93 percent), or dicalcium phosphate (100 percent).

Application and Performance: Lenis and Schutte (1990) showed that the protein content of a typical Dutch swine ration could be reduced by 30 grams per kilogram without negative effects on animal performance. They calculated that a 1 percent reduction in feed N could result in a 10 percent reduction in excreted N. Monge et al. (1998) confirmed these findings by concluding that a 1 percent reduction in feed N yielded an 11 percent reduction in excreted N. According to Van Kempen and Simmins (1997), reducing the variation of nutrients in feed by using more appropriate quality control measures would reduce N waste by 13 to 27 percent. Experts believe that N losses through excretion can be reduced by 15 to 30 percent in part by minimizing excesses in diet with better quality control at the feed mill (NCSU, 1998).

Plant geneticists have produced strains of corn that contain less phytate-P (i.e., low-phytate corn) and are more easily digested than typical strains, resulting in less P excreted in manure. Allee

[1] Most plant P occurs in the form of phytate, which is P bonded to phytic acid.

and Spencer (1998) found that hogs fed low-phytate corn excreted an average of 37 percent less P in manure, with no adverse effects on animal growth. In a study by Bridges et al. (1995), two weight classes of grow-finish pigs (66.1 and 101.7 kg) were given maize-soybean meal diets lower in protein and P to determine the reduction in N and P in pig waste when compared with pigs fed a conventional diet. Total N waste was reduced by 32 and 25 percent for the two weight classes, while total P excretion was reduced by 39 and 38 percent, respectively. The study also modeled the impact of reductions in dietary protein and P over the complete grow-finish period using the NCPIG model developed by the North Central Regional Swine Modeling Committee. Model results showed a reduction of approximately 44 percent in total N and P excretion compared with the conventional diet, with little impact on the time of production. In addition, the Fédération Européenne des Fabricants d'Adjuvants pour la Nutrition Animale in Belgium (FEFANA, 1992) calculated that the selection of highly digestible feedstuffs should result in a 5 percent reduction in total waste.

Advantages and Limitations: Precision feeding results in a higher feed efficiency (less feed used per pound of pig produced); however, any cost savings are at least partially offset by the cost of analyzing the nutrient content of feedstuffs. Consumer reaction to use of genetically modified crops to feed swine has not been determined yet.

Operational Factors: Precision feeding requires that feed manufacturers have the necessary equipment and procedures to create precision feeds within specified quality control limits. In general, feed manufacturers have traditionally limited quality control to measuring N, which correlates poorly with amino acid content in feedstuffs (van Kempen and Simmins, 1997). Precision feeding will also increase the costs and complexity of feed storage at the feeding operation.

Demonstration Status: Data on the frequency of use of precision nutrition are not available. Much of the information available on precision nutrition is derived from small-scale research experiments at the USDA and universities.

Practice: Multiphase and Split-Sex Feeding for Swine

Description: Multiphase feeding involves changing diet composition weekly instead of feeding only two different diets during the period from the 45-kg size to slaughter. Multiphase feeding is designed to better match the diet with the changing nutritional requirements of the growing animals.

Application and Performance: Feeding three or four diets during the grow-finish period instead of only two diets will reduce N excretion. According to models such as the Dutch Technical Pig Feeding Model by van der Peet-Schwering et al. (1993), multiphase feeding reduces N and P excretion by 15 percent. The modeling results have been confirmed by animal trials that showed a 12.7 percent reduction in N excretion in urine and a 17 percent reduction in P excretion.

Advantages and Limitations: Dividing the growth period into more phases with less spread in weight allows producers to meet more closely the pig's protein requirements. Also, because gilts (females) require more protein than barrows (males), separating barrows from gilts allows lower protein levels to be fed to the barrows without compromising leanness and performance efficiency in the gilts.

Operational Factors: Multiphase and split-sex feeding require separate feeding areas and pens for the different types of animals. It is also more costly to produce a different feed every week.

Demonstration Status: The *Swine <95* report (USDA APHIS, 1995) showed that 96.2 percent of grow/finish operations fed two or more different diets. Of these operations, 63.4 percent progressed to a different diet based on animal weight, 5.3 percent changed diets based on either age or the length of time on the feed, and 30.0 percent based diet changes on equal consideration of weight and time. Of the 96.2 percent of grow-finish operations that fed more than one diet, 18.3 percent practiced split-sex feeding. Split-sex feeding is used much more frequently in medium (2,000–9,999 head) and large operations (10,000+ head) than in small operations (less than 2,000 head).

Practice: Improved Feed Preparation for Swine

Description: Milling, pelleting, and expanding are examples of technological treatments that improve the digestibility of feeds. By reducing the particle size, the surface area of the grain particles is increased, allowing greater interaction with digestive enzymes. NCSU (1998) reported that the industry average particle size was approximately 1,100 microns and that the recommended size is between 650 and 750 microns. Expanders and extruders are used mainly to provide flexibility in ingredient selection and to improve pellet quality rather than to improve nutrient digestion.

Application and Performance: As particle size is reduced from 1,000 microns to 700 microns, excretion of N is reduced by 24 percent. Vanschoubroek et al. (1971) reviewed many articles regarding the effect of pelleting on performance and found that not only did animals prefer pelleted feed over mash feed, but feed efficiency improved by 8.5 percent and protein digestibility improved by 3.7 percent with pelleted feed.

Advantages and Limitations: Although reducing particle size less than 650 to 750 microns can increase feed digestibility, it also greatly increases the costs of grinding and reduces the throughput of the feed mill. Smaller-sized particles can also result in an increased incidence of stomach ulcers in animals. In some cases, chemical changes resulting from the high temperatures created in grinding machines may decrease feed digestibility.

Operational Factors: A reduction in the particle size of the feed might result in manure with finer solids particles. This may affect the performance of manure management practices including possible effects on the efficiency of manure solid-liquid separators.

Demonstration Status: Data on the frequency of use of feed preparation techniques are not available.

Practice: Feed Additives for Swine

Description: Enzymes are commonly used in feed to improve the digestibility of nutrients. For example, plant P is often present in the form of phytate, which is digested poorly in swine, resulting in most of the P in feedstuffs being excreted in the manure. To prevent P deficiency, digestible P is added to swine rations, resulting in even more P in the manure. The enzyme additive phytase has been shown to improve P digestibility dramatically, and can be used to reduce the need for digestible P additives.

Other enzyme additives facilitate the retention of amino acids and digestive fluids, decreasing the amount of N excreted. Enzymes such as xylanases, beta-glucanases, and proteases upgrade the nutritional value of feedstuffs. Xylanases and beta-glucanases are enzymes used to degrade nonstarch polysaccharides (NSP) present in cereals such as wheat and barley. Swine do not secrete these enzymes and therefore do not have the capability to digest and use NSP. Because the NSP fraction traps nutrients that are released only upon partial degradation of the NSP fraction, addition of xylanase or beta-glucanase or both to cereal-containing diets can result in improvements in both digestibility and feed efficiency. In addition, supplementing the diet with synthetic lysine to meet a portion of the dietary lysine requirement is an effective means of reducing N excretion by pigs. This process reduces N excretion because lower-protein diets can be fed when lysine is supplemented. The use of other amino acid feed supplements is being tested.

Application and Performance: Mroz et al. (1994) showed that phytase increases P digestibility in a typical swine diet from 29.4 to 53.5 percent. They also demonstrated that phytase addition improved the digestibility of other nutrients in the feed such as Ca, Zn, and amino acids that are bound by phytase. For example, the addition of phytase to a commercial diet increased the digestibility of lysine by 2 percent while the digestibility of protein improved from 83.3 to 85.6 percent. Van der Peet-Schwering (1993) demonstrated that the use of phytase reduced P excretion by 32 percent in nursery pigs (a finding similar to the FEFANA [1992] predictions). Lei et al. (1993) found that feeding pigs 750 phytase units per gram of basal diet yielded a decrease in fecal P excretion of 42 percent without adverse health effects. This addition resulted in a linear improvement in phytate-P utilization. Graham and Inborr (1993) reported that enzyme additions improved the digestibility of protein in a wheat/rye diet by 9 percent.

Beal et al. (1998) used proteases on raw soybeans and observed a significant improvement in daily gain (+14.8 percent); feed efficiency, however, was improved by only 4.3 percent. Dierick and Decuypere (1994) saw a substantial improvement in feed efficiency when using proteases in combination with amylases and beta-glucanases, an improvement larger than that achieved with each enzyme individually. Studies have shown that protein levels can be reduced by 2 percent when the diet is supplemented with 0.15 percent lysine (3 pounds lysine-HC1 per ton of feed) without harming the performance of grow-finish pigs.

Advantages and Limitations: Feed additives, especially synthetic amino acids and enzymes, increase the cost of feeding. Phytase, for example, was once too expensive to use as a feed additive. This enzyme can now be produced at lower cost with recombinant DNA techniques. As technology improves, it is likely that the costs associated with other feed additives will decrease similarly.

Operational Factors: The level of phytase required in swine feed varies with the age of the animal. These different levels are likely determined by the development of digestive enzymes and intestines of the pig, with the younger pig being less developed. Lysine supplements can be used to achieve even greater reductions in the level of protein in diets, but only if threonine, tryptophan, and methionine are also supplemented.

Demonstration Status: The use of proteases in animal feeds is not widespread because of conflicting results from trials. With the advancement of enzyme-producing technology, as well as a better understanding of the role of enzymes in animal nutrition, proteases and other enzymes (e.g., pentosanases, cellulase, and hemicellulases, as tested by Dierick, 1989) are likely to play a greater role in animal nutrition. As their costs come down, the Amino Acid Council foresees an increased use of synthetic amino acids as a method of reducing N excretion as well as improving animal performance and decreasing feeding costs.

8.1.1.2 Poultry Feeding Strategies

Poultry operators have traditionally employed feeding strategies that focus on promoting animal growth rates or maximizing egg production. Feed additives have also been used to prevent disease and enhance bone and tissue development. As noted in Chapter 4, productivity has increased dramatically over the past several decades. The decrease in the average whole-herd feed conversion ratio (pounds of feed per pound of live weight produced) has translated into reduced feed input per bird produced. Smaller feed requirements can mean decreased manure output, but, until recently, development of better feeding strategies and advances in genetics have not focused on manure quality or quantity generated. Environmental issues associated with animal waste runoff have compelled the poultry industry to look for improved methods of waste prevention and management including feeding regimes that can reduce the nutrient content of manure.

Dietary strategies to reduce the amount of N and P in manure include developing more precise diets and improving the digestibility of feed ingredients through the use of enzyme additives and genetic enhancement of cereal grains.

Practice: Precision Nutrition for Poultry

Description: Precision nutrition entails formulating feed to meet the animals' nutritional requirements more precisely, causing more of the nutrients to be metabolized, thereby reducing the amount of nutrients excreted. For more precise feeding, it is imperative that both the nutritional requirements of the animal and the nutrient yield of the feed are fully understood. Greater understanding of poultry physiology has led to the development of computer growth models that take into account a variety of factors including strain, sex, and age of bird, for use in implementing a nutritional program. By optimizing feeding regimes using simulation results, poultry operations can increase growth rates while reducing nutrient losses in manure.

Application and Performance: The use of improved feeds tailored to each phase of poultry growth has improved productivity significantly. Feed conversion ratios for broilers and turkeys have decreased steadily over the past several decades. Egg production productivity has also been boosted as operators have introduced improved nutrient-fortified feed.

Advantages and Limitations: Improved precision in feeding strategies offers numerous advantages including reduction of nutrients in animal manure and better feed conversion rates. Improved formulations are also cost-effective and reduce the probability of wasteful overfeeding of poultry.

Operational Factors: Precision nutrition requires detailed knowledge of poultry nutritional requirements and maintenance of detailed records to ensure that dietary adjustments are performed in a timely manner to maximize growth potential.

Demonstration Status: The use of precise nutrient formulations has already generated large increases in productivity in the poultry sector. Many of the poultry operations are under contract and receive feedstuffs with precise formulations from the integrator. Ongoing research will likely continue to result in productivity improvements.

Practice: Use of Phytase as a Feed Supplement for Poultry

Description: P, an essential element for poultry growth and health, is typically added to poultry feed mixes. However, because poultry are deficient in the enzyme phytase and cannot break down the protein phytate, much of the P contained in feed cannot be digested (Sohail and Roland, 1999). Because poultry cannot produce phytase, up to 75 percent of the P contained in feed grains is excreted in manure (NCSU, 1999).

One feeding strategy used by poultry operators to reduce P levels in manure is to add microbial phytase to the feed mix.[2] This enzyme is produced by a genetically modified fungus, *Aspergillus niger*. The final enzyme product is usually available in two forms, a powder or a liquid (Miller, 1998). The phytase enzyme reduces P excretion by releasing the phytate-P contained in the cell walls of feed grains. The released P can then be absorbed by the bird's intestine and used for its nutrient value. A secondary beneficial effect of using phytase is that manure P content is further reduced because less inorganic P needs to be added to poultry diets (Edens and Simons, 1998).

Application and Performance: Phytase can be used to feed all poultry. P reductions of 30 to 50 percent have been achieved by adding phytase to the feed mix while simultaneously decreasing the amount of inorganic P normally added (NCSU, 1999).

[2]As noted in Chapter 4, some experts believe phytase should not be provided to poults because of the enzyme's adverse effect on bone development in turkeys, while other experts believe it will enhance growth.

Advantages and Limitations: Addition of phytase to feed significantly reduces P levels in poultry manure. The high cost of phytase application equipment has discouraged more widespread use.

Operational Factors: Because phytase is heat-sensitive, it must be added to broiler and turkey feeds after the pelleting process (NCSU, 1999). The phytase is added by spraying it on the feed. This can result in uneven distribution and variable doses. Studies have shown that phytase efficacy is related to calcium, protein, and vitamin B levels in a complex manner. Further, phytase efficacy can be degraded by excess moisture, which can be a problem if mash (wet) feed is used for broilers (Miller, 1998). The shelf life of phytase is usually not a problem, because feed is typically consumed within 2 weeks or less at most operations.

Demonstration Status: Phytase is in use at many poultry operations. Application equipment for adding phytase to large volumes of feed is undergoing field testing.

Practice: Genetically Modified Feed for Poultry

Description: Using genetically modified animal feed offers poultry operators another way to reduce P levels in bird manure. In 1992, a research scientist at the USDA Agricultural Research Service developed a nonlethal corn mutant that stored most of its seed P as P rather than as phytate. The total P content in the mutant corn was the same as that found in conventional corn, except that there was a 60 percent reduction in phytic acid. The P released by the reduction in phytic acid P becomes available to the consuming animal as inorganic P (Iragavarapu, 1999).

Application and Performance: Genetically modified feed can be used for all poultry types. The potential for reducing P levels is quite large. One variety of corn with a high available P content has 35 percent of the P bound in the phytate form compared with 75 percent for normal corn (NCSU, 1999). Recent tests of a new hybrid corn, developed by USDA and the University of Delaware, demonstrated a 41 percent decrease in P levels in manure. Soluble P levels in waste decreased by 82 percent, compared with the amount produced by poultry fed a standard commercial diet (UD, 1999).

Advantages and Limitations: New hybrid varieties of grain can increase poultry utilization of plant P. Adding phytase to the modified feed further reduces manure P levels and can eliminate the need for nutrient supplements. The increased cost of feed and phytase additives might limit their use.

Operational Factors: The use of genetically modified feed would not differ from the use of conventional feed, although the increase in available nutrients in the feed would diminish the need for supplements.

Demonstration Status: Since its discovery in 1992, the mutant corn has been made available to commercial companies for further research, development, and commercialization of hybrid grains. Some hybrid varieties are currently used; others are in the research or demonstration stage. As more of these products are developed and prices are lowered, the use of hybrid grains combined with enzyme additives will likely increase.

Practice: Other Feeding Strategies to Reduce Nutrient Excretion for Poultry

Poultry operators use additives other than phytase to reduce manure nutrient content. These additives include synthetic amino acids and protease, and they are designed to facilitate more efficient digestion of N compounds and allow the use of smaller proportions of nutrients in feed while not adversely affecting animal growth rates and health. Researchers have also demonstrated that feed enzymes other than phytase can boost poultry performance and reduce manure production (Wyatt, 1995). Enzymes currently added to barley and wheat-based poultry feed in Britain and Europe include xylanases and proteases. Currently, the use of additives such as synthetic amino acids and enzymes could significantly increase feed costs. These costs, however could be expected to decrease over time as the technology matures and is more widely used by animal feed operators.

8.1.1.3 Dairy Feeding Strategies

Feeding strategies to reduce nutrient losses from dairy operations, primarily N and P, are focused on improving the efficiency with which dairy cows use feed nutrients. A more efficient use of nutrients for milk production and growth means that a smaller portion of feed nutrients ends up in manure. Elimination of dietary excess reduces the amount of nutrients in manure and is perhaps the easiest way to reduce on-farm nutrient surpluses (Van Horn et al., 1996). Reducing dietary P is the primary practice being used; however, a number of related management strategies also reduce nutrient levels in the manure by increasing the efficiency with which dairy cows use feed nutrients. These strategies include measuring the urea content of milk, optimizing feed crop selection, and exposing cows to light for a longer period of the day.

Practice: Reducing Dietary Phosphorus for Dairy Cattle

Description: Reducing the level of P in the diets of dairy cows is the primary and most important feeding strategy for reducing excess nutrients given because P plays a central role as a limiting nutrient in many soils; evidence indicates that dairy operators, as a whole, are oversupplying P in dairy diets; and there is an imbalance in the N to P ratio in cow manure, which favors reductions of P to produce a more balanced fertilizer. Reducing the amount of P in dairy diets has also been shown to reduce production costs and increase overall profitability.

The 2001 edition of the National Research Council's (NRC) nutrient requirements for dairy cows recommends dietary P levels of 0.32 to 0.44 percent of dry matter for dairy cows in lactation depending on breed and milk production rate (NRC, 2001). Dietary P in excess of these requirements has been shown to have no beneficial effect on animal health or production. Most excess P passes through the cows' systems and is excreted as manure, which is later applied to land. Rations, however, typically average 0.48 percent P or more (Satter and Wu, 2000). Supplemental feeding of dicalcium phosphate—often the second most expensive component in dairy cow diets—is the usual practice by which a dairy cow's rations achieve this level. A number of studies have addressed the adequacy of current dietary P recommendations. These studies include Steevens et al., 1971; Tamminga, 1992; McClure, 1994; and Chase, 1998.

Application and Performance: This practice should be applicable to all dairy operations. The amount of manure P resulting from a given level of dietary P is estimated using the following equation (Van Horn, 1991):

$$\text{Manure P} = 9.6 + 0.472 \times (\text{Intake P}) + 0.00126 \times (\text{Intake P})^2 \text{ B } 0.323 \times \text{Milk}$$

Manure and intake P are measured in grams, and milk production is measured in kilograms. Based on this formulation, assuming that each lactating cow produces on average 65 pounds of milk a day, Table 8-1 quantifies reductions in manure P resulting from reduced P intake (Keplinger, 1998). Four scenarios are considered: a 0.53 percent P diet, which is considered the baseline, and three reduced P diet scenarios. Comparing the 0.40 percent scenario against the baseline, P intake during lactation is reduced by 25 percent, while manure P is reduced by 29 percent. During the entire lactation period, manure P is reduced by 14.63 pounds per cow from the baseline level of 50.45 pounds per cow. For the entire year (lactation and nonlactation periods), manure P per cow is reduced by 27 percent.

Table 8-1. Per Cow Reductions in Manure P Resulting from Reduced P Intake During Lactation.

Percentage of P in Diet	Daily		Manure P (lb)		Reduction from Baseline (0.53%)		
	P Intake (lb)	Manure P (lb)	During Lactation	Entire Year	Amount (lb)	During Lactation	Entire Year
0.53	0.265	0.165	50.5	55.1	0.0	0	0
0.49	0.245	0.150	45.8	50.4	4.7	9	8
0.46	0.230	0.139	42.4	47.0	8.1	16	15
0.43	0.215	0.128	39.1	43.7	11.4	23	21
0.40	0.200	0.117	35.8	40.4	14.6	29	27

Advantages and Limitations: Supplemental feeding of dicalcium phosphate to dairy cows represents a substantial expense to dairy farmers—the second most expensive nutrient in a herd's mixed ration (Stokes, 1999). The economic advantages of reducing supplemental P, based on a study on the Bosque River watershed of Texas (Keplinger, 1998), suggest that a dairy operator who adopts a 0.40 percent P diet compared with the baseline 0.53 percent diet would save $20.81 per cow annually. A survey of scientific literature on the subject reveals no adverse impact on either milk production or breeding from reducing dietary P to NRC-recommended levels.

Another advantage to producers is the impact of reduced manure P on land application practices. Many states incorporate a P trigger in manure application requirements. For example, in Texas, state regulation requires waste application at a P rate (versus an N rate) when extractable P in the soil of an application field reaches 200 parts per million (ppm). Applying manure with a lower P concentration would slow and possibly eliminate the buildup of P in application fields, thereby delaying or eliminating the need to acquire or transform more land into waste application fields. When manure is applied at a P rate, greater quantities can be applied if it contains a lower P concentration. Thus, application fields would require less chemical N, because manure with lower P concentrations is a more balanced fertilizer. In addition, reduced land requirements for waste application fields would represent substantial savings to dairy producers in cases in which a P application rate is followed.

Operational Factors: It is possible that factors such as climate, temperature, and humidity, as well as operation-specific factors, influence the effectiveness of steps taken to reduce dietary P; however, there are no published studies that address this issue. Dairy cows, for instance, are more prone to disease in moist climates and suffer heat stress in hot climates. Average milk production per cow varies greatly across geographic regions of the United States—averaging 21,476 pounds in Washington state versus only 11,921 pounds in Louisiana (USDA, 1999). Because dairy cow productivity and health are influenced by climate, it is likely that climate may also influence the effectiveness of nutrient-reducing feeding strategies, particularly those which depend on productivity gains. The magnitude and even the direction of the influence of factors such as temperature, humidity, and the like on nutrient-reducing feeding strategies, however, have not been established.

Demonstration Status: Dairy rations typically average 0.48 percent P or more (Satter and Wu, 2000), much higher than the NRC recommendation of 0.44 percent. A survey of milk producers in north Texas by a milk producers' organization indicated dietary P averaged 0.53 percent. A 1997 survey of professional animal nutritionists in the mid-South Region (Sansinena et al., 1999), indicates nutritionists' recommendations of dietary P averaged 0.52 percent, or 30 percent higher than the high end of NRC's current recommendation. Survey respondents cited several reasons for recommending final ration P in excess of NRC standards: almost half of the respondents (15 of 31) expressed a belief that lactating cows require more P than suggested by the NRC (Sansinena et al., 1999). The next most prevalent reason given was that a safety margin was required. Justifications for the safety margin included a lack of confidence in published ingredient P values and concern for variable P bioavailability in feed ingredients. Professional opinion also suggests that dietary P in dairy cow diets averages around 0.52 percent throughout the nation, although this percentage may be declining. Because of the heightened awareness of both the environmental benefits and the cost savings attainable by reducing P in dairy cow diets, some operators have adopted the NRC recommendation. Recent articles in dairy trade magazines have recommended adoption of the NRC standard for both environmental and economic benefits.

Practice: Milk Urea N Testing for Dairy Cattle

Description: There have been significant developments recently in the use of milk urea N (MUN) as a method for testing and fine-tuning dairy cow diets for protein feeding. Measured MUN concentrations are used as a proxy for the nutritional well-being of the cow.

Research has shown that mean MUN concentration levels from a group of cows should fall into specific ranges. By comparing the results of MUN tests with these ranges, the tests can be used as a monitoring tool to evaluate a herd's protein nutritional status. For cows fed at optimal dry matter intake, expected mean values of MUN concentrations range from 10 to 14 milligrams per deciliter (mg/dL) (Ferguson, 1999; Jonker et al., 1998). Field studies of MUN levels of dairy herds in Pennsylvania (using a very large sample—312,005 samples) have reported average MUN concentrations of 14 mg/dL (Ferguson, 1999). Implicit in this level is that even allowing for the inherent large variability of MUN testing, the diets of some herds contain excess MUN levels that have no economic value; this also suggests that N in manure can be reduced by reducing excess N in dairy diets. The importance of reducing dietary protein levels is highlighted in a study (Van Horn, 1999) that estimates that for every 1 percent reduction in dietary protein, excretion of N may be reduced by 8 percent.

Application and Performance: This practice should be applicable to all dairy operations. The elimination of excess dietary protein with the use of the MUN test to evaluate protein levels in dairy cow feeds could reduce N levels in manure by 6 percent (Kohn, 1999). In addition, further methods to improve N utilization in dairy cows and raise the efficiency of feed delivery may be revealed by MUN testing.

Advantages and Limitations: Through MUN testing and the evaluation of other variables, farmers can identify which cows are eating too much protein, and fine-tune diets, thereby reducing N output in manure. Advantages of MUN testing are the possibilities of reducing ration costs by eliminating excess protein and improving the efficiency of feed delivery (Kohn, 1999). A disadvantage of animal group feeding strategies is that they become more difficult to set up and manage as group size decreases. The cost-effectiveness of custom feeding individual cows is as yet unproven.

Operational Factors: The large variability within and between herds and breeds of cows limits the usefulness of MUN testing, but it does not reduce the test's important role as a monitor of ration formulation.

Demonstration Status: This practice is primarily at the research stage and has not become widespread.

Practice: Diet Formulation Strategies for Dairy Cows

Description: Diet formulation strategies have received new examination. Alternative diet formulations to the NRC recommendations—notably the Cornell Net Carbohydrate and Protein model (CNCPS) (Sniffen et al., 1992)—that are more complicated than the NRC recommendations have been developed and suggest feeding about 15 percent less protein to a herd at the same level of production for certain conditions (Kohn, 1996). Evaluations of the CNCPS model's performance have been mixed, and further research is needed.

Theoretically, protected amino acid supplements have the potential to be part of an important strategy in increasing the efficiency of protein use by dairy cows, thereby reducing N losses. If amino acid supplements can be made effectively for dairy cows (avoiding rumen-associated problems), they could replace large portions of a dairy cow's protein intake. In theory, protected amino acid supplements could significantly reduce N intake and hence N levels in manure. In practice, the benefits of using protected amino acid supplements may not be as dramatic because the need to balance diet formulations may create limitations.

Application and Performance: This practice should be applicable to all dairy operations. Some evaluation of the alternative diet formulation suggested by the CNCPS implies a significant increase in milk production (from 24,100 pounds/cow per year to more than 26,000 pounds/cow per year) and a large reduction in N excretion (of about one-third) (Fox et al., 1995). More recent evaluations using two different large data sets (Kalscheur et al., 1997; Kohn et al., 1998) present mixed results, with the CNCPS performing better in some aspects and the NRC recommendations in others. Thus, results of the CNCPS evaluation should be considered preliminary. In theory, the use of protected amino acid supplements has great potential to improve nutrient efficiency. A typical lactating cow is assumed to require 1.1 pounds per day of N intake; by successfully substituting protected methionine and lysine for feed protein, this N intake and resulting manure N could be dramatically reduced (Dinn et al., 1996), but this research is preliminary.

Advantages and Limitations: Alternative diet formulations could improve nutrient efficiency. Information on limitations is unknown at this time, and EPA is continuing research in this area.

Operational Factors: The cost of preparing and storing multiple feed stuffs limits the use of this practice to the number of diets that the operator feels justifies the additional expense. Additional research on this practice is needed.

Demonstration Status: This practice is primarily at the research stage and has not become widespread.

Practice: Animal Feed Grouping for Dairy Cows

Description: Grouping strategies offer another method of realizing gains in nutrient efficiency. When grouping does not occur and the whole herd receives the same diet, cows may receive suboptimal diets and nutrient export to manure may be greater. Using grouping strategies to their greatest effect to improve nutrient efficiency would entail individualized diets. Feeding strategies already reviewed, such as the MUN concentration test, can be used in conjunction with grouping strategies or individual diets.

Application and Performance: This practice should be applicable to all dairy operations. Grouping strategies have been shown to reduce nutrient intakes and manure nutrients. When all the lactating cows are fed together according to current recommendations, they consume 7 percent more N and P, and 10 percent more nutrients are excreted in manure, compared with the individualized feeding strategy. Half of the gains of individualized diets could be achieved with two groups (Dunlap et al., 1997).

Advantages and Limitations: This practice could improve nutrient efficiency. Information on limitations is unknown at this time.

Operational Factors: As noted under diet formulation strategies, the cost of preparing and storing multiple feedstuffs limits the use of this practice to the number of diets that the operator feels justifies the additional expense. Additional management input is also required in separating the animals into groups.

Demonstration Status: Dairy operations currently employ a range of grouping strategies (from no grouping to individual diets) to improve the efficiency of feed nutrients.

Practice: Optimizing Crop Selection

Description: Optimizing crop selection is another potential strategy for reducing nutrient losses in combination with dairy diets to meet annualized herd feed requirements with minimal nutrient losses. In whole-farm simulation of various crop strategies (corn silage, alfalfa hay, and a 50:50 mixture) the 50:50 mixture was judged to have performed best (when evaluated by N losses per unit of N in milk or meat) (Kohn et al., 1998). Converting dairy operations from confined to pasture operations is also considered a strategy for reducing nutrient loss on a per cow or operation basis. Kohn's model, however, found that a strategy of grazing versus confinement for lactating cows produced higher N loss per unit of milk produced because the decline in milk production was greater than the decline in manure nutrients (Kohn et al., 1998).

Application and Performance: This practice should be possible at operations that have sufficient land. In simulation of crop selection strategies involving whole-farm effects, mixed alfalfa hay and corn silage (50:50) was judged the best strategy for minimizing nutrient flows from the farm. Nitrogen losses were minimized to 2.9 units for every unit of N in meat or milk, compared with a loss of 3.5 units in the corn-based strategy, a 21 percent reduction (Kohn, 1999). Phosphorus accumulations did not tend to vary among the different strategies.

Advantages and Limitations: Optimal crop selection based on whole-farm effects suggests that the strategy that was most nutrient efficient in terms of N loss per unit of N in meat and milk is also the strategy that gains the most productivity from N; this strategy might, therefore, be the most cost-effective (Kohn et al., 1998). A grazing (versus confinement) strategy may or may not be cost-effective depending on the structure of individual dairy operations.

Operational Factors: Unknown at this time.

Demonstration Status: This practice is primarily at the research stage and has not come into widespread use.

Practice: Increasing Productivity

Description: The literature suggests that there are several feeding strategies that focus on increasing productivity as a route to nutrient efficiency. While the focus is on increased milk production, an important associated benefit of these strategies is that they result in greater milk production per unit of nutrient excreted. One approach involves exposing dairy cows to light for longer daily periods of the day through the use of artificial lighting. A longer daily photoperiod (18 hours light/6 hours dark) increases milk yields relative to those of cows exposed to the natural photoperiod (Dahl et al., 1996).

Application and Performance: This practice should be applicable at all operations that confine their animals. The artificial lighting technology to extend the daily photoperiod of dairy cows to 18 hours a day has been shown to be effective in increasing the nutrient efficiency of the farm. For an increase in milk production of 8 percent the herd's feed nutrients would be required to increase by only 4.1 percent, and N and P excretions would rise by only 2.8 percent when compared to a typical herd without artificial lighting (Dahl et al., 1996, 1998).

Advantages and Limitations: The artificial lighting technology is expected to be cost-effective. It is estimated that the initial investment in lighting can be recouped within 6 months. One observed advantage of milking three times a day rather than twice a day is that it reduces stress on the herd (Erdman and Varner, 1995). Because of the increased labor involved, the economic advantage of milking three times a day is variable and dependent on the individual farm (Culotta and Schmidt, 1988).

Operational Factors: To use this practice many dairy operations would need to install and operate additional lights.

Demonstration Status: This practice is primarily at the research stage and has not come into widespread use.

8.1.2 Reduced Water Use and Water Content of Waste

This section presents practices that reduce the water content in the waste stream. The production of a drier waste can be accomplished by three methods: (1) handling the waste in a dry form, (2) reducing the use of water at the AFO, or (3) separating the solid fraction of the waste from the liquid fraction. Most poultry operations currently handle their waste in a dry form, and this section generally does not apply to these operations.

Practice: Dry Scrape Systems *and the Retrofit of Wet Flush Systems*

Description: Scraper systems are a means of mechanically removing manure, and they can be used to push manure through collection gutters and alleys similar to those used in flush systems. For best results, scrapers should have a minimum depth of 4 inches in open gutters and 12 to 24 inches in underslat gutters (MWPS, 1993).

Retrofitting a wet flush system with a dry scrape system involves reconstructing the existing manure handling equipment within a livestock housing structure. A scraper blade replaces flowing water as the mechanism for removing manure from the floor of the structure.

In flush systems, large volumes of water flow down a sloped surface, scour manure from the concrete, and carry it to a manure storage facility. There are three basic types of flush systems: underslat gutters, narrow-open gutters, and wide-open gutters or alleys. Underslat gutters are used primarily in beef confinement buildings and swine facilities in which animals are housed on slats to prevent disease transmission as a result of animals coming into contact with feces. Narrow-open gutters are typically less than 4 feet wide and are used predominately in hog finishing buildings. Wide-open gutters or alleys are most often seen in dairy freestall barns, holding pens, and milking parlors. The water used in a flush system can be either fresh or recycled from a lagoon or holding basin (Fulhage et al., 1993; MWPS, 1993).

Application and Performance: Removing manure with a scraper is appropriate for semisolid and slurry manure, as well as drier solid manure. The flush system is an appropriate means of removal for both semisolid and slurry manure. Retrofitting a flush system to a scraper system appears to be most feasible in underslat gutters and wide alleys. A major concern to be addressed is the discharge area of the scraper. Existing collection gutters, pumps, and pipes used in a flush system will likely be inadequate for handling the undiluted manure product.

Replacing a flush system with a dry scrape system dramatically reduces the amount of water used in manure handling and also reduces the tonnage of manure by decreasing dilution with water. There are several options for storing manure from a scrape system, including prefabricated or formed storage tanks, from which contaminants are less likely to seep.

Retrofitting a flush system with a scrape system will not treat or reduce pathogens, nutrients, metals, solids, growth hormones, or antibiotics. The concentrations of these components will actually increase with the decrease in water dilution.

Advantages and Limitations: In a building with a scrape system, the manure removed from the livestock housing area is in slurry or semisolid form (depending on species) and no water need be added. Compared with a wet flush system, the resulting manure product has a greater nutrient density and increased potential for further treatment and transportation to an area where the manure product is needed as a fertilizer. A large lagoon is usually necessary for storing and treating flush waste and water; handling manure in a drier form, on the other hand, significantly decreases the volume and tonnage of the final organic product. Although this is an important advantage when it is necessary to transport manure to areas where there is an increase in available land base, it can be a disadvantage in that an irrigation system would not be able to transport the thicker slurry that results from the use of a scrape system.

The greater volume of contaminated water and waste created in a flush system generally dictates that storage in a large lagoon is required. There are more options for storing manure removed with a scrape system. These storage alternatives may be more suited to practices that reduce odors (e.g., storage tank covers), more appropriate for areas with karst terrain or high water tables, and more aesthetically desirable.

The drawbacks of using a scrape system rather than a flush system include an increased labor requirement because more mechanical components need maintenance, a higher capital outlay for installation, an increased requirement for ventilation, and less cleanliness. Using a flush system to remove manure results in a cleaner and drier surface with less residual manure and less in-house odor, thus creating a better environment for livestock. Furthermore, alleys can be flushed without restricting animal access. As mentioned above, the discharge area of the scraper is a concern. Existing pumps and pipes may be unable to handle the undiluted manure. Moreover, a completely new manure storage structure might be needed (Vanderholm and Melvin, 1990).

Operational Factors: Both the scrape and flush systems have disadvantages when used in open barns during winter months, but a scrape system is more likely to function properly at lower temperatures.

If alleys are straight with continuous curbs, alley scrapers can usually be installed, but alley lengths of up to 400 feet in dairy freestall barns may make installation of scraping systems impractical. Scrapers work best when they can be installed in pairs of alleys so the chain or cable can serve each and form a loop. It might be necessary to cut a groove into the concrete alley for the chain or cable to travel in. The decision of whether to cut a channel or let the chain rest on the pavement is best left to the manufacturer. It should be noted that maintenance requirements associated with the chain and cable will likely be high because of corrosion caused by continuous contact with manure. Hydraulic scrape units that operate on a bar and ratcheting blade are also available (Graves, 2000).

Demonstration Status: The use of scrape systems and the practice of retrofitting a flush system are not common in the livestock industry. Inquiries regarding the use of this practice have been made to manure management specialists, agricultural engineers, and manufacturers of scraper systems. Very few professionals indicated that they had any experience in the area or were aware of the practice being used. Those professionals willing to comment on the implications of retrofitting seemed to believe that it would be most feasible and advantageous on dairies (Graves, 2000; Jones, 2000; Lorimor, 2000; Shih, 2000).

Practice: Gravity Separation of Solids

Description: Gravity settling, separation, or sedimentation is a simple means of removing solids from liquid or slurry manure by taking advantage of gravitational forces. The engineering definition of a settling or sedimentation tank is any structure that is designed to retain process wastewater at a horizontal flow rate less than the vertical velocity (settling rate) of the target particles.

In agricultural applications, gravity settling is a primary clarification step to recover solids at a desired location where they can be managed easily, thereby preventing those solids from accumulating in a downstream structure where they would be difficult to manage. A wide range of gravity separation practices are used in agriculture including sand and rock traps, picket dams, and gravity settling basins designed to retain 1 to 12 months' accumulation of solids.

Settling tanks can be cylindrical, rectangular, or square. Agricultural settling tanks have been made with wood, metal, concrete, and combinations of materials. Some are earthen structures. In agriculture, gravity separation is sometimes accomplished without a recognizable structure including techniques such as a change in slope that allows particles to settle when the liquid velocity drops.

The critical design factor in sedimentation tanks is surface overflow rate, which is directly related to the settling velocity of particles in the wastewater (Loehr, 1977). Faster settling velocities allow for increased surface overflow rates, while slower settling velocities require decreased overflow rates to remove settleable particles. In "ideal" settling, the settling velocity (Vs) of a particle is equal to that particle's horizontal velocity (VH), where

VH = Q/DW
Q is the flow through the tank
D is the tank depth
W is the tank width

The ASAE has defined several types of gravity separation techniques (ASAE, 1998):

- Settling Channels: A continuous separation structure in which settling occurs over a defined distance in a relatively slow-moving manure flow. Baffles and porous dams may be used to aid separation by further slowing manure flow rates. Solids are removed mechanically once liquids are fully drained away.
- Settling Tank: A relatively short-term separation structure, smaller in size than a settling basin. The liquid is allowed to fully drain away for solids removal by mechanical means.
- Settling Basin: A relatively long-term separation structure, larger in size than a settling tank. Solids are collected by mechanical means once the liquids evaporate or have been drained away.

Application and Performance: Gravity separation is relatively common in the United States. Separation is used to reduce clogging of downstream treatment or handling facilities. Reduced clogging means improved lagoon function and better wastewater treatment. Most beef feedlots in the Midwest and Great Plains use gravity separation ponds to collect solids from rainfall runoff, thus improving the function of runoff collection ponds. Gravity separation basins are used across the country on hog farms to reduce solids accumulation in tanks or lagoons they discharge to. It is likely that more dairies with flush systems use gravity settling for solids recovery rather than mechanical separators to preserve lagoon capacity.

Table 8-2 shows the substantial range of treatment efficiencies for gravity settling of manure. The performance of a gravity separation basin depends on the design goal and ability of the operator to maintain the system in design condition. Performance will vary with animal type, animal feed, dilution water, flow rate, percent of capacity already filled with solids, temperature, and biological activity. The data ranges in Table 8-2 may be explained in part by the time span separating the studies. More recent studies show reduced solids recovery from swine manure. This may be partly due to the fact that animal diets have changed over the years, with feed more digestible and more finely ground these days. Further, feed is ground to different particle sizes that have different settling characteristics, thus potentially affecting separation basin performance. In addition, ruminants are fed materials that have different settling characteristics than those fed to nonruminants. Process variables such as overflow velocities are seldom reported in the literature, but they are important determinants of separation basin performance. Extra water from processing or precipitation and already settled material will increase the flow rate across a settling basin, reducing settling time and solids capture. In many agricultural settling basins, biological activity resuspends some settled materials which then pass through the separator. At best, one can conclude from these data that gravity settling can recover in swine wastes a larger percentage of total solids (TS), volatile solids (VS), and total N (TN) than another separation technique reviewed for the practice, mechanical solid-liquid separation, that follows in this chapter.

Table 8-2. Performance of Gravity Separation Techniques.

Recovered in Separated Solids, Percent						
	TS	**VS**	**TN**	**P_2O_5**	**K**	**COD**
Swine (Moser et al., 1999)	39–65	45–65	23–50	17–50	16–28	25–55
Beef (Edwards et al.,1985; Lorimore et al., 1995) and Dairy (Barker and Young, 1985)	50–64	NA	32–84	20–80	18–34	NA

TS=Total solids; VS=volatile solids; TN=total nitrogen; P_2O_5=pyrophosphate; K=potassium, COD=chemical oxygen demand.

Because of short return times, pathogen reduction through settling is minimal; however, settling might reduce worm egg counts. No information is available on growth hormones in manure or on how settling might affect growth hormones that may be found in manure. Degradation of antibiotics usually hinders their detection in manure, and no information is available on the effect of settling on antibiotics in manure.

Taiganides (1972) measured 80 to 90 percent recovery of copper, iron, zinc, and P with settled swine solids. The study also reported that 60 to 75 percent of the sodium, K, and magnesium settled and was recovered.

Advantages and Limitations: The main advantage of gravity settling is the relatively low cost to remove solids from the waste stream. Recovering solids prevents the buildup of those solids in ditches, pipelines, tanks, ponds, and lagoons. Dairy solids consist mostly of fiber and can be composted and recycled as cow-bedding material, or they can be composted and sold as a soil amendment. Swine solids are finely textured, hard to compost aerobically, and rapidly degraded to odoriferous material if handled improperly. Beef solids collected from lot runoff can become odoriferous if left in a separation basin, but they can be composted for sale to crop farms, nurseries, or soil products companies.

Collected solids are a more concentrated source of nutrients than the separated liquid, resulting in decreased hauling costs per ton of nutrient. The separated liquid has a reduced nutrient content and can be applied to a smaller acreage than the original material.

Disadvantages of solids separation include the need to clean out the separator, the potential odor emitted from the basin, the odor produced by solids removed from the basin, and attraction of insects and rodents to the separated solids. Additional costs are incurred when the solids and liquids from pig manure are managed separately.

Operational Factors: Solids separators do not function if they are frozen or experience horizontal flow rates higher than the solids settling rate. Solids tend to separate better at warmer temperatures.

Demonstration Status: Gravity separation is the most common solids separation technique in use in the United States.

Practice: Mechanical Solid-Liquid Separation

Description: Solids-liquid separation is used to recover solids prior to their entry into downstream liquid manure facilities. Solids recovery reduces organic loading and potential accumulation of solids and improves the pumping characteristics of animal manure. Mechanical separation equipment is used to reduce the space required for separation, to produce a consistent separated solid product amenable to daily handling, to produce a liquid product that is easily pumped for spreading, or to recover specific particle sizes for other uses such as bedding.

Mechanical separation equipment is readily available for animal wastes. Mechanical separators include static and vibrating screens, screw press separators, rotary strainers, vacuum filters, centrifugal separators, belt filter presses, and brushed screen/roller presses. Static screens are the most popular mechanical separators because they are inexpensive to buy, install, and operate. All other mechanical separation techniques are less common.

Static screens are usually mounted above grade on a stand to allow solids accumulation beneath. Barn effluent is typically pumped up to the screen, where the liquids pass through while the solids collect on the screen surface. Screens are typically inclined, causing accumulating solids to slide down from the screen toward collection. There are multiple configurations with different screen designs, screen materials, screen opening spacing, influent distribution, post-use washdown, and additional pressing of separated solids.

Vibrating screens are flat or funnel-shaped screens supported on springs and oscillated by an eccentric drive. The vibrations cause the solids to move from the screen for collection.

With screw presses, manure is pumped to the base of a turning open-flight auger that goes through a screen tube made of welded wire, wedge wire, perforated metal, or woven screen material. Solids collect on the screen, forming a matrix as the auger advances them. A tensioned opening restricts the flow of materials up the auger and out from the tube. The retained material is squeezed by the auger against the screen tube and tensioned opening until it overcomes the tension and exits. The matrix acts as a filter allowing the collection of finer particles than are collected by other types of screens. The auger wrings liquid from the separated solids by forcing material against the plug of material held by the tensioned opening and screen tube.

A rotary strainer is a slowly rotating, perforated cylinder mounted horizontally. Waste flows by gravity onto the cylinder at one end, where solids are scraped from the cylinder surface and moved to the exit end. Liquids pass through the screen for collection and removal (ASAE, 1998). Vacuum filters are horizontally mounted, rotating perforated cylinders with a cloth fiber cover. A vacuum is used to draw liquids from the wastewater. Wastewater flows onto the cylinder surface, liquids pass through the screen, and solids are scraped from the cloth at a separation point (ASAE, 1998).

A centrifugal separator, or centrifuge, is a rapidly rotating device that uses centrifugal force to separate manure liquids from solids. One type, a relatively low-speed design, uses a cylindrical or conical screen that can be installed vertically or horizontally. Manure is fed into one end, and solids are then contained by the screen, scraped from it, and then discharged from the opposite end. The liquid passes through the screen. A second type, a higher-speed decanter, uses a conical bowl in which centrifugal force causes the denser solids to migrate to the bowl exterior where they are collected. Less dense liquids are forced to the center for collection (ASAE, 1998).

A belt press is a roller and belt device in which two concentrically running belts are used to squeeze the manure as it is deposited between the belts. The belts pass over a series of spring-loaded rollers where liquids are squeezed out or through the belt, and remaining solids are scraped off at a belt separation point (ASAE, 1998).

Brush screen presses are rectangular containers with four vertical sides and a bottom consisting of two half-cylindrical screens lying side by side to provide two stages of separation. Within each screen rotates a multiple-brush and roller assembly that sweeps the manure across the screen. Manure is pumped into one side of the separator. The liquids are forced through the screen by the brush/roller while the solids are retained by the screen and pushed from the separator on the opposite side (ASAE, 1998).

Application and Performance: Mechanical separation is used to reduce clogging of downstream treatment or handling facilities. The use of this practice to preserve lagoon capacity by separating solids is relatively common among dairies using flush manure collection. Reduced clogging means improved lagoon function and better wastewater treatment. Mechanical separation of solids from manure, however, is relatively rare because of the added costs.

Table 8-3 shows the range of treatment efficiencies for the mechanical separation of manure. These systems do not perform as well as gravity separation, but they produce a more consistent product delivered as a solid for easy collection. Most manufacturers and owners are less concerned about the percentage of recovery or the properties of the recovered material than they are about the TS concentration of the separated solids. Performance will vary with animal type, animal feed, dilution water, flow rate, percent of capacity already full of solids, temperature, and biological activity. In general, pig manure has finer solids than cow manure, and recovery of pig manure constituents is in the low end of the ranges in Table 8-3, whereas cow manure constituent recovery is in the upper portion of the range.

Table 8-3. Summary of Expected Performance of Mechanical Separation Equipment.

Separation Technique	Recovered in Separated Solids, Percent				
	TS	**VS**	**TN**	**P_2O_5**	**COD**
Stationary screen	10–25	10–25	5–15	10–20	5–20
Vibrating screen	10–20	10–20	10–20	0–15	10–20
Screw press	20–30	20–30	10–20	20–30	20–40
Centrifuge	40–60	40–60	20–30	25–70	30–70
Roller drum	20–30	20–30	10–20	10–15	10–25
Belt press/screen	40–60	40–60	30–35	15–20	30–40

Source: Moser et al., 1999.

Pathogen reduction through mechanical separation is negligible. No information is available on growth hormones in manure or on the effect of mechanical separation on growth hormones that may be found in manure. Degradation of antibiotics usually hinders their detection in manure, and no information is available on the effect of mechanical separation on antibiotics in manure.

No significant information was found on the effect of mechanical separation on heavy metal content of either the solids or the liquids. Work in gravity separation suggests that metals are associated with fine particle sizes that would pass with the liquids through mechanical separation.

Static (stationary) screens are most commonly used for separating solids from dilute solutions with solids concentrations of 5 percent or less. The more dilute the solution, the more likely that discrete particles will be collected on the screen because there is less particle-versus-particle interference. The dilute solution also washes finer particles from larger, retained particles and through the screen.

Vibrating screens are used for separating solids from dilute solutions with solids concentrations of 3 percent or less. Vibrating screens will generally process more flow per unit of surface area than static screens because the vibrating motion moves the solids from the screen. Vibrating screens are more sensitive than static screens to variations in solids content and wastewater flow (Loehr, 1977).

Static screens and vibrating screens usually collect 10 to 15 percent of the TS from manure. An owner generally selects a screen that will not easily clog, or blind (i.e. one with larger screen spacing), instead of choosing an optimized screen and feed pump to avoid both screen blinding, when the slurry thickness changes, and the creation of a soggy solids pile.

Screw presses can handle thicker materials than most separators, and are used to separate manures that have between 0.5 and 12 percent TS. Chastain et al. (1998) noted, however, that a screw press did not separate well unless the TS content of the waste was above 5 percent. Because screw presses first allow the solids to form a matrix and catch fine solids, the percent solids recovery is generally greater than for other solids separators. The screw press is designed to produce drier solids (up to 35 percent). Solids recovery is dependent on the screen tube openings and the setting of the retaining tension. The higher the tension is set, the harder the screw squeezes the separated material, and the more solids are forced out through the screen. Tighter settings for drier solids may significantly affect the useful life of both auger and screen.

Belt presses are expensive, require a trained operator, operate best with chemical addition, and cannot process rocks and barn parts found in manure. With or without chemical addition, however, they can do a good job of separating 40 percent or more of the TS. Nevertheless, the cost of belt presses, plus the extremely high cost of maintenance and the need for continuous operator presence, makes their use problematic.

The primary advantage of centrifugation over other separators appears to be in the reduction of total P, but centrifugation is also clearly more efficient than screening for removal of all constituents. Managed by trained operators, centrifuges will recover over 60 percent of the TS. Nevertheless, the large capital cost, the need for trained operators, and the high maintenance costs have made this equipment impractical for farm use.

Advantages and Limitations: The main advantages of mechanical separation are the consistent level of solids removal from the waste stream and the delivery of separated solids at a recovery location. Recovering solids prevents the buildup of those solids in ditches, pipelines, tanks, ponds, and lagoons. Dairy solids, which consist mostly of fiber, can be composted and recycled as cow bedding material. Dairy solids have also been composted and sold as a soil amendment. Swine solids are finely textured, hard to compost aerobically, and rapidly degraded to odoriferous material if handled improperly.

Collected solids are a more concentrated source of nutrients than the separated liquid, resulting in decreased hauling costs per ton of nutrient. The separated liquid has a reduced nutrient content and can be applied to a smaller acreage than the original material.

Disadvantages of solids separation include operation and maintenance requirements, potential odor production from collection basins and separated solids, and attraction of insects and rodents to the separated solids. Additional costs are incurred when the solids and liquids in swine manure are managed separately.

Operational Factors: Mechanical solids separators do not function if the manure or the face of the machine is frozen, but they can operate under a wide variety of other conditions.

Demonstration Status: Mechanical solids separation is being used at thousands of dairies and perhaps several hundred hog farms. Regarding specific technologies, static screens are most commonly used, whereas vibrating screens and rotary strainers are seldom used on farms today. Vacuum filters are infrequently used on farms because inorganic materials such as rocks and metal bits tend to rip the filter fabric. High capital and operating costs have limited farm use of centrifugal separators. Brush screen presses may occasionally be found on farms, but the low throughput rate has limited its use. Screw presses are in use at a few hundred dairy farms, but at a very limited number of swine farms in the United States.

Practice: Two-Story Hog Buildings

Description: The two-story, High-RiseJ hog building design (Menke et al., 1996) integrates manure collection, storage, and treatment in a single, enclosed facility. The building is designed to pen approximately 1,000 head of hogs on the second floor of a two-story building, with a dry manure collection and storage system on the first (ground) level. The second floor features solid side walls and totally slatted floors. The manure falls through the slats to the first floor area, which is covered with 12 to 18 inches of a dry bulking agent such as sawdust, oat or wheat straw, corn fodder, or shredded newspaper. The design includes sliding doors on the ground level to allow for tractor and loader access.

The building's unique, two-fold ventilation system maintains superior air quality in the swine holding area and dries the manure in the storage area (Figure 8-1). Clean air is pulled from the ceiling through continuous baffle inlets and is directed down over the swine vertically (with no horizontal, pig-to-pig air movement). Air exits the swine holding area through the floor slats and is pulled horizontally to the outside of the first-floor pit area by 14 computer-controlled ventilation fans mounted on the pit walls. This system prevents air from the manure pit from rising to the animal area. The second part of the ventilation system involves pumping air through the manure by floor aeration. PVC pipes with approximately 3,200 3/8-inch holes are installed before the concrete floor is poured. Two large fans on either end of the building force air through perforations in the concrete and into the composting mixture on the ground floor.

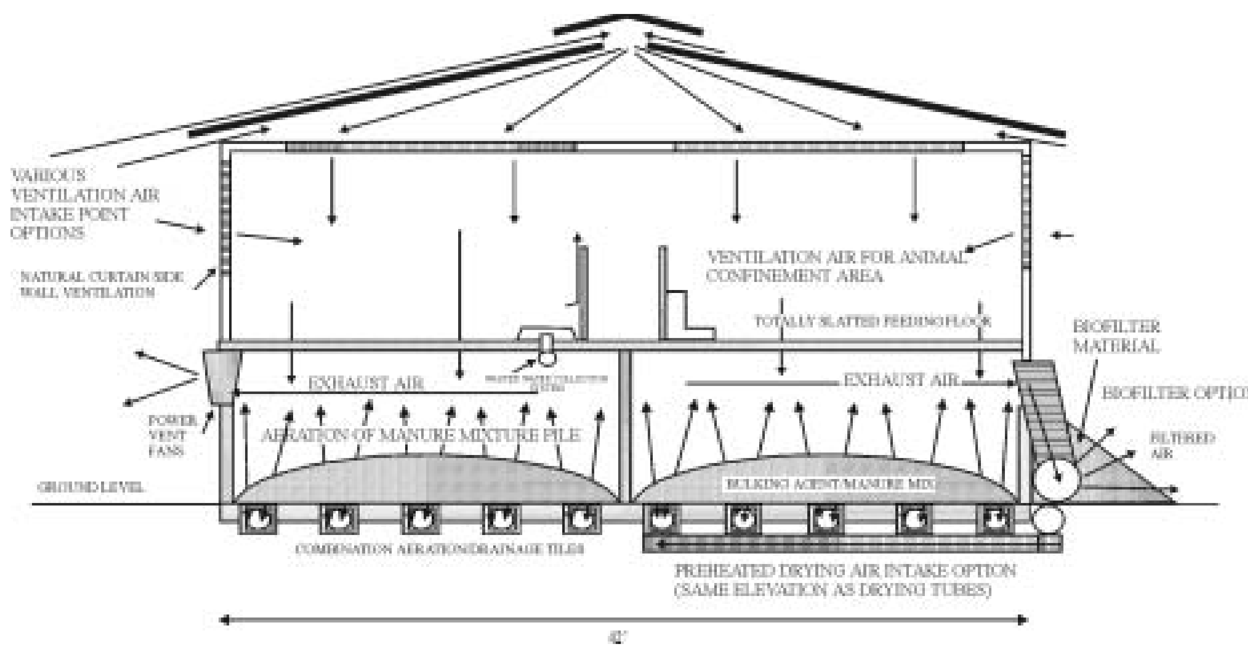

Figure 8-1. High-Rise Hog Building

Application and Performance: Management practices, swine care, and feeding are much the same as with conventional confinement. The High Rise facility is distinctive because it incorporates dry manure handling and storage into a traditional confinement production scenario. The system dries the manure mixture and maintains an aerobic environment to facilitate the composting process. Drying and homogeneity of the mixture are also facilitated by mixing with a tractor and loader or skid-steer loader. Frequency of mixing varies from once per production cycle to biweekly, depending on the saturation of bedding. The semicomposted bedding mixture is removed once per year and can be further composted, land applied, or sold. A typical 1,000-head unit produces 500 tons of semicomposted product per year.

The High Rise facility is best suited for areas where there is limited local land base for manure application; sandy, porous soils; limited water supply; or an existing market for compost or partially composted material.

The aerobic decomposition that occurs within the pit results in a significant volume reduction in the manure. In fact, initial trials have shown that loading the pit with 12 to 18 inches (approximately 11 tons) of bedding results in only 2.5 to 3 feet of manure to be removed at the end of 1 year. This is estimated as a 22 percent reduction in manure volume and a 66 percent reduction in manure tonnage (Envirologic, 1999; Mescher, 1999). These figures are based on a final product with 63 percent moisture. When compared with liquid/slurry hog manure that is approximately 90 percent moisture, this presents a great advantage in areas where there is a lack of local land base and manure must be transported more than 3 to 4 miles to alternative areas for application. Manure with 63 percent moisture is considered to be in dry form and can be hauled in a semi truck with an open trailer rather than in a liquid tanker pulled by a tractor.

The aerobic decomposition and drying that reduce the volume and tonnage of the final organic product do not result in a reduction of the overall nutrient content. In fact, with the exception of N and sulfur (some of which volatilizes) nutrients will be more concentrated in the resulting semicomposted product. The semicomposted manure is four times more concentrated than liquid manure from treatment lagoons.

The High-Rise facility incorporates both manure treatment and storage in a completely aboveground handling system. In addition, the ground-level manure storage area is enclosed in poured concrete. This is especially advantageous in sites with porous soils or fragmented bedrock. Such locations are unfit or, at the least, potentially dangerous areas for earthen basin and lagoon construction due to concerns regarding ground water contamination. Furthermore, belowground concrete pits have an increased potential for ground water pollution if leaking occurs in a region with porous soils or fragmented bedrock. The aboveground concrete manure storage of the High-Rise building allows visual monitoring for leakage.

Information is not currently available on the reduction of pathogens, heavy metals, growth hormones, or antibiotics in the manure product as it is removed from the High-Rise facility. However, research on some of these topics is currently underway. Based on the composition of the product, temperature readings within the manure pack, and knowledge of the composting process, several speculations can be made. Destruction of pathogens in the composting process is a result of time and temperature. The higher the temperature within the manure pack, the less time it takes to eliminate pathogens. In general, the temperature within the manure pack needs to exceed the body temperature of the animal and pathogen destruction is most effective at 120 °F or higher. Temperature readings taken in the manure pack in the High-Rise facility ranged from only 45 to 78 °F (Keener, 1999). The predominant reason for the manure packs not reaching a high enough temperature is the continuous aeration provided. It is unlikely that there is a significant reduction of pathogens at this temperature. There may be some decrease in pathogen numbers due to the length of time (up to one year) the manure pack remains in the building. Further composting of the manure pack once it is removed from the High-Rise structure would allow the product to reach temperatures high enough for complete pathogen destruction.

The composting process has no effect on the quantity of heavy metals in the manure. Further, because of the decrease in volume and tonnage of the manure, heavy metals will be more concentrated. Composting does, however, influence the bioavailability of the metals, causing them to be less mobile. The extent to which the mobility of heavy metals is decreased in the semicomposted product removed from the High-Rise facility is unknown.

The degree to which growth hormones and antibiotics degrade during the composting process is unknown and is not widely studied.

Designers of the High-Rise facility claim a savings of 1.8 million gallons of water per 1,000 head of hogs annually when compared with a conventional pull-plug flush unit. This conservation results from using wet-dry feeders and eliminating the addition of water for manure removal and handling. A reduction in the amount of water used in the system results in less waste product to be handled.

Advantages and Limitations: As explained above, the dry manure handling system used in the High-Rise facility significantly decreases the volume and tonnage of the final organic product. This is an important advantage when transportation to areas where there is an increased land base for manure application is necessary. However, because the semicomposted product has greater concentrations of macronutrients, with the possible exception of N (which might volatilize), the number of acres needed to correctly apply the manure does not decrease. N volatilization during the composting process creates the possibility of upsetting the nutrient balance in manure. For example, if manure was applied to land with the application rate based on the amount of N in the manure, P and potassium could be applied at rates 10 times the recommended rate. This problem is eliminated if application rates are based on the P content of manure. Additional commercial N application might be necessary depending on the crop being produced.

Data from an initial trial show that the manure product removed from the High-Rise facility has a fertilizer value of about $19 per ton at 60.7 percent moisture, with an organic matter content of 29.8 percent. Secondary studies show that the manure mixture is of adequate content for further composting, which is necessary to sell manure commercially. These factors create an increased opportunity to broker manure and possibly provide supplemental income to the swine production enterprise (Envirologic, 2000).

Observations and data resulting from the first year of study in the High-Rise structure indicate that there is a significant decrease in odor using the dry manure handling system. NH_3 measurements on the swine housing level averaged from 0 to 8 ppm, with an overall mean of 4.3 ppm and spikes of up to 12 ppm in times of decreased ventilation (winter months). In a conventional confinement building with a deep, liquid pit, ammonia levels of 20 to 30 ppm are commonplace. NH_3 levels on the ground level of the High-Rise building vary inversely with building ventilation and have exceeded a short-term exposure rate of 50 ppm in the winter. It must be realized, however, that the basement level is not occupied during normal conditions. Large sliding doors are opened when the facility is cleaned to let in fresh air and facilitate the entry of a tractor/loader. NH_3 levels external to the outside exhaust fans averaged 23.3 ppm, but quickly dissipated (Keener et al., 1999).

No hydrogen sulfide gas was detected in the swine holding area. Levels on the first floor were minimal (National Hog Farmer, 2000). Decreased levels of these potentially toxic gases improve air quality and prevent excessive corrosion in the building.

Producers who plan to build a High-Rise facility can expect a 15 percent increase in capital outlay compared to a 1,000-head, tunnel ventilation finisher with an 8-foot-deep pit. Cost projections prepared for the company that manufactures the High-Rise building indicate that reduced cost for manure handling and transportation offsets the additional building cost (Envirologic, 2000). Solid manure handling is less automated than many liquid manure handling systems. Although solid systems have lower capital costs, labor costs are higher than those associated with liquid systems. Labor costs are expected to be less than traditional scrape and haul systems because the slatted floors eliminate the need to scrape animal areas frequently.

In addition to the increased capital requirement, the cost of utilities is also elevated. Additional energy is needed to power the many ventilation fans. Electricity usage averages roughly twice that of a naturally ventilated confinement barn. Accounting for all of these factors, the cost of production in a High-Rise facility is approximately $180 per pig. This is 28 to 30 percent greater than the cost of production in a confinement structure with a shallow pit, and 15 to 18 percent greater than in a more conventional deep pit (Mescher et al., 1999).

The ventilation system that pumps air over the swine holding area keeps the swine and slats dry, resulting in cleaner swine and fewer injuries. Also, there is no flow of air from pig to pig, which helps prevent airborne transmission of disease. The combination of decreased moisture and exceptional air quality leads to improved animal health and decreased medication costs.

Data from a single High-Rise facility show that animal performance was the same or better than that of conventional facilities with respect to average daily gain, days to market, feed conversion, mortality, and the number of culls. In fact, the decreased number of days to market translates into 0.2 to 0.3 more production cycles per year, creating potential to increase profits significantly.

It is speculated that improvement in performance measures is due to better air quality (Envirologic, 2000).

Leachate from the manure mixture appears to be minimal if mixing is done on a regular basis. Rodents in the basement pit might become a problem if control measures are not taken.

Operational Factors: Artificial climate control and ventilation in the building make the High-Rise building appropriate in most climates . It is estimated that air in the building is exchanged every 10 to 15 seconds, providing an environment of uniform temperature and humidity throughout the building year-round. Over a 1-year span, the mean air temperature taken from several test areas within the building varied only ± 2 °F from the desired temperature. There were, however, differences of up to 10 °F between testing areas on the swine floor (Stowell et al., 1999). The building is equipped with a standard sprinkling system for use in hot summer months.

Demonstration Status: The High-Rise facility technology has been tested with finisher pigs since 1998 at a single research facility in Darke County, Ohio. The vendor has built four commercial grow-finish buildings since that time and they are currently in production in west central Ohio. The vendor is also developing prototypes for other phases of swine production using the same manure handling system.

Practice: Hoop Structures

Description: Hoop structures are low-cost, Quonset-shaped swine shelters with no form of artificial climate control. Wooden or concrete sidewalls 4 to 6 feet tall are covered with an ultraviolet and moisture-resistant, polyethylene fabric tarp supported by 12- to 16-gauge tubular steel hoops or steel truss arches placed 4 to 6 feet apart. Hoop structures with a diameter greater than 35 feet generally have trusses rather than the tubing used on narrower hoops. Some companies market hoops as wide as 75 feet. Tarps are affixed to the hoops using ropes or winches and nylon straps.

Generally, the majority of the floor area is earthen, with approximately one-third of the south end of the building concreted and used as a feeding area. The feeding area is designed with a slight slope (1 to 2 percent) to the outside of the building in case of a waterline break, and is raised 12 to 19 inches above the earthen floor to keep the feeding area clear of bedding material. Approximately 150 to 200 finisher hogs or up to 60 head of sows are grouped together in one large, deep-bedded pen. The building should be designed so that the group housing area provides approximately 12 square feet of space per finisher pig, or 27 square feet per sow.

Hoop structures are considered a new and viable alternative for housing gestational sows and grow-finish pigs. Gestational housing systems being used in the United States are modeled after conventional Swedish style, deep-bedded gestation and breeding housing. In Sweden today, deep-bedded housing systems with individual feeding stalls are the conventional method of dry sow housing. There are feeding stalls for each sow, with connecting rear gates and individually opening front gates, a deep-bedded area for the group-housed sows, and bedded boar pens. The stalls are raised approximately 16 inches above the ground to accommodate the deep-bedding pack in the center.

In each production scenario, plentiful amounts of high quality bedding are applied to the earthen portion of the structure, creating a bed approximately 12 to 18 inches deep. The heavy bedding absorbs animal manure to produce a solid waste product. Additional bedding is added continuously throughout the production cycle. Fresh bedding keeps the bed surface clean and free of pathogens and sustains aerobic decomposition. Aerobic decomposition within the bedding pack generates heat and elevates the effective temperature in the unheated hoop structure, improving animal comfort in winter conditions.

Application and Performance: The hoop structure originated in the prairie provinces of Canada. Recently, interest in this type of structure has increased in Iowa and other states in the Midwest. Swine production in this type of facility is most prevalent for finishing operations, but is also used to house dry gestational sows. Other possible uses in swine production include gilt development, isolation facilities, housing for light pigs, breeding barns, farrowing, and segregated, early weaning swine development. A hoop structure is an appropriate alternative for moderately sized operations. An “all in, all out” production strategy must be used with finishing pigs.

The manure from hoop structures is removed as a solid with the bedding pack. The high volume of bedding used creates an increased volume of waste to be removed. Typically, a front-wheel assist tractor with a grapple fork attachment on the front-end loader is required to clean out the bedding pack. In a finishing production system, the bedding pack is removed at market time, usually two to three times per year. In gestational sow housing, slightly less bedding is required, and the bedding pack is typically removed one to four times a year depending on the stocking density and quality of bedding.

A limited amount of information is available on the manure characteristics, both inside the hoop and during consequent manure management activities. The manure content within the pack is highly variable. Dunging areas are quickly established when swine are introduced into the deep-bedded structure. These areas contain a majority of the nutrients within the pack. Results of an Iowa State University study are shown in Table 8-4. Samples were taken on a grid system at nine areas throughout the bedding pack (three samples along the west side of the building, three along the center, three along the east).

Temperatures throughout the bedding pack also varied greatly. Bedding temperature was highest in the sleeping/resting area where the moisture content is approximately 50 percent. Bedding temperatures were lowest in the wet dunging areas that contain 60 to 70 percent moisture. The lower temperatures were likely caused by anaerobic conditions that prevent oxidation of carbon and, therefore, reduce the amount of heat generated (Richard et al., 1997; and Richard and Smits, 1998).

Table 8-4. Examples of Bedding Nutrients Concentrations.

Bedding Nutrients by Location[a]				
Site	**Total Moisture (percent)**	**Total Nitrogen (lb/ton)**	**Phosphorus (lb/ton)**	**Potassium (lb/ton)**
West1	73.7	20	21	12
West2	75.2	22	22	12
West3	68.5	22	31	16
Center1	67.4	14	20	26
Center2	22.9	11	21	37
Center3	27.6	22	17	26
East1	68.5	29	24	29
East2	30.6	36	40	51
East3	73.5	16	13	15
Mean	56.4	21.3	23.2	24.8
Standard Deviation	22.3	7.6	7.6	13

[a] Adapted from Richard et al., 1997.

Richard et al. and Richard and Smits (1997, 1998) also examined the loss of N in the hoop structure bedding pack. One-third of the N was lost while swine were housed in the structure. This loss was hypothesized to be caused largely by NH_3 volatilization and possibly from nitrate leaching. An additional 10 percent reduction in N occurred as the bedding pack was removed from the hoop. This loss was also hypothesized as being a result of NH_3 volatilization. Additional N was lost during the composting process, with the amount lost corresponding to the specific composting process demonstrated. In general, the composting process that resulted in the greatest reduction of volume also had the greatest N loss (Richard and Smits, 1998).

N leaching potential was examined in yet another study at Iowa State University. The hoop facility used in this trial was located on hard-packed soil with a high clay-content. Following one production cycle, the surface NO_3-N was 5.5 times greater than the initial level. There was no significant change in NO_3-N at other depths ranging to 5 feet. Following a second production cycle, the NO_3-N levels at all depths to 5 feet increased three times compared with those taken following the initial production cycle (Richard et al., 1997). Nitrate was the only form of N tested.

The Medina Research Centre in Australia studied N and P accumulation in the soil beneath hoop structures. The hoop structures were constructed on Swan Coastal Plain sandy soils. Two trials were conducted in the same location approximately 6 weeks apart. In each trial there was no increase in the concentration of extractable P in the soil profile when compared with baseline data (Jeffery, 1996).

Advantages and Limitations: The quality of the work environment in a deep-bedded hoop structure is generally good. There is no liquid manure and therefore less odor than with conventional systems. The building structure and recommended orientation provide for a large volume of naturally ventilated air. Also, because the manure is solid, storage requirements are minimized.

The high degree of variability within the bedding pack makes it difficult to predict nutrient content. Some areas can have a high fertilizer value, whereas others have high carbon and low N content. The latter can lead to N immobilization and result in crop stress if applied during or immediately prior to the growing season.   For these reasons, it is desirable to mix the bedding pack to achieve a higher degree of uniformity. Some mixing will occur during the removal and storage of the manure. Treatments that allow for additional mixing, such as composting in windrows, appear to offer considerable benefits. Initial studies at Iowa State University found that composting improved uniformity, and provided for a 14 to 23 percent reduction in moisture and a 24 to 45 percent reduction in volume (Richard and Smits, 1998). It should be noted that bedding from gestational sow facilities is typically drier than that from finishing facilities. The lack of moisture is likely to limit the extent of composting unless additional manure or moisture is added.

Trials comparing a conventional confinement system to hoop structures have been performed at Iowa State University. The swine raised in the hoop structure experienced similar performance. Specifically, there was a low level of swine mortality (2.6 to 2.7 percent), comparable and acceptable average daily gain, and a slightly poorer feed efficiency (8 to 10 percent) for swine raised in the winter months (Honeyman et al., 1999). Poor feed efficiency in winter months is due to an increased nutrient/energy requirement to maintain body heat. These findings supported an earlier study by the University of Manitoba that found swine finished in hoop structures to have excellent health, similar rates of gain, poorer feed efficiency in colder months (10 to 20 percent), low swine mortality, and similar days to market (Conner, 1993). Moreover, similar results were found in a South Dakota State University study. Several researchers have identified proper nutrition for swine raised in hoops as an area needing further research.

With respect to housing dry gestational sows, providing a lockable feeding area for each sow affords similar advantages to those of traditional gestation crates. Producers have the ability to keep feed intake even, eliminate competition for feed, administer treatments and medication effectively, lock sows in for cleaning and bedding, and sort and transfer sows for breeding or farrowing through the front gates. Furthermore, group housing stimulates estrus (the period of time within a female’s reproductive cycle in which she will stand to be bred), reduces stress to the sow, and alleviates many foot and leg problems common in sows. Fighting is minimized by the use of feeding stalls and introducing new sows at optimal times, such as farrowing. Concreting the deep-bedded section to prevent sows from rooting is an option, but it increases capital outlay (Honeyman et al.,1997).

Iowa State University has conducted demonstration trials on gestating sows in deep-bedded hoop structures. Conception rate, farrowing rate, number of swine born alive, and birth weight in groups gestated in the hoop structure were all excellent. The sow performance results indicate that hoop structures are an exceptional environment for gestating sows. It must be noted, however, that sow groups were not mixed and new sows were not introduced during the trial.

With respect to breeding, hot weather is of greater concern than cold weather. Excessive high temperatures can be detrimental to breeding performance. Boars exposed to elevated effective temperatures will experience poor semen quality for a 6- to 8-week period that begins 2 to 3 weeks following exposure. Sows are more tolerant to high temperatures, except during the first 2 to 3 weeks of gestation and the final 2 weeks prior to farrowing. Litter size and birth weight can be severely altered during these periods (Honeyman et al., 1997).

Iowa State University has also conducted preliminary trials with farrow-to-finish production, early weaned pigs, and wean-to-finish production. These studies concluded that, although each may be a viable alternative, many details must still be worked out before they all become successful consistently.

The hoop system offers several benefits with respect to animal welfare and behavior. Honeyman et al. (1997) stated that one of the most extreme stresses in livestock production results when an animal is prevented from controlling various aspects of its environment. This lack of control is apparent in many of today's conventional production systems and is responsible for an unduly high level of stress that affects general health, reproduction, and welfare. Production in a deep-bedded hoop structure allows each animal to control its own microenvironment by burrowing down into the bedding, huddling, or lying on top. Deep-bedded hoops also allow swine to root through and ingest some bedding at will. This is especially advantageous in dry-sow gestational housing. The behavior serves two purposes. First, swine have an inherent drive to root. Being able to do so prevents frustration, boredom, and, hence, aggression. Second, consumption of bedding material quiets any hunger the pig may feel. Increased genetic evolution has led swine to have an increased drive to eat. Gestating sows are typically fed a limited amount of feed, satisfying what is estimated to be only 30 to 50 percent of their appetite. Stereotypic behavior is indicative of a suboptimal environment and will ultimately have implications on an animal's general health and production. No evidence of stereotypic behavior is cited in any of the deep-bedded system studies (Honeyman et al., 1997).

The initial capital outlay for hoop structures is about 30 percent less than the capital requirement associated with a typical double-curtain swine finishing building (Harmon and Honeyman, 1997). Additionally, hoop structures are highly versatile and have many alternative uses (e.g., equipment storage) if production capacity is not needed. Production in hoop structures requires a greater amount of feed and large volumes of high quality bedding, however. Bedding is the key to successful production in hoop structures. These differences make the cost of production comparable to that of a traditional confinement setting.

Hoop structures are easy to construct with on-farm labor. In Iowa State University trials, hoop structures show no visible signs of deterioration after 4 years (Honeyman, 1995). The average useful life of a hoop structure is estimated to be 10 years (Brumm, 1997).

The amount of bedding used in the studies averages 200 pounds per finisher pig in each production cycle, with a greater amount of bedding being used in the winter months. It is estimated that approximately 1,800 pounds of high quality bedding per gestational sow are needed each year (Halverson, 1998). The amount of labor is directly proportional to the amount of bedding and ranges from 0.3 to 0.6 hours per pig (Richard et al., 1997). A survey distributed to producers of finishing pigs in hoop structures and compiled by Iowa State University found actual labor requirements to average 0.25 hours per pig (Duffy and Honeyman, 1999). Labor requirements rely on many factors, including farm size, level of automation, and experience with the production system. Based on the trials conducted at each university, the labor requirement was considered to be reasonable and competitive with other finishing systems (Conner, 1993; Richard et al., 1997).

The large amount of bedding required in hoop structure production can limit its feasibility for some producers. Many types of bedding can be used. Corn stalks, oat straw, wheat straw, bean stalks, wood shavings, and shredded paper have all been used with some success, although shredded corn stalks are the most common. Selection of the appropriate bedding type is based on many factors. First, the availability of bedding must be considered. This is specific to geographical area but may also be limited by climate. An early snow or a wet fall could prevent stalk baling. Second, in several areas of the Midwest, federally mandated conservation plans on highly erodible land require residue to be left on the land. In such cases, harvesting corn and bean stalks may not be appropriate. Finally, bedding storage is an important consideration. Generally, bedding baled in the fall and used by the spring can be stored outdoors. Bedding needed for spring and summer use, however must be stored undercover in a well-drained area to avoid loss in quality and quantity.

Internal parasite control must be aggressive because swine are continually in contact with their feces. Several of the Iowa State University studies note that flies are a potential problem for hoop houses in warm months. Furthermore, rodent and bird problems may be difficult to control. Also, in the summer, incidental composting within the bedding pack can create unwelcome heat and may lessen the animals' comfort. It has not been determined whether there is severe potential for disease and parasite buildup in the soil beneath the hoop structure.

Operational Factors: Production in a hoop structure relies on bedding, intensive management, and keen husbandry for success. Climate control is a major factor in determining the feasibility of deep-bedded hoop structures. The recommended orientation of the buildings is north to south (depending on geographical area), to take advantage of the prevailing summer winds. Air enters the facility through spaces between the sidewall and the tarp and at the ends. Warm, moist air moves toward the top of the arch and is carried out the north end by natural currents. Various end structures are available that supply adjustable levels of ventilation. In the winter months, the north end is generally closed and the south is at least partially opened. If the ends are closed too tightly, high levels of humidity can become a problem. On average, the inside air temperature in the winter is only 5 to 8 °F warmer than outside temperatures. This is different from the effective temperature which the swine can alter by burrowing into the deep bedding. In summer months, both ends are left open. Ultraviolet resistant tarp and sprinklers inside the structure help to control the temperature within the structure. Air temperature in the summer averages 2 to 4 °F lower than outside temperature (Harmon and Xin, 1997). The length of the hoop structure also has an effect on air temperature because of the rate of air exchange. Wider and longer hoop structures often have ridge vents to improve ventilation.

Demonstration Status: Hoop structures have been used successfully in the United States for housing finishing pigs and dry gestational sows. Grow-finish production is the most common use for hoop structures in swine production. Recently, there has been an increased interest in this type of production system in the Midwest, including the states of Iowa, Illinois, Minnesota, Nebraska, and South Dakota. It is estimated that more than 1,500 hoop structures have been built for swine production in Iowa since 1996 (Honeyman, 1999). Furthermore, initial demonstrations have been conducted with early weaned pigs and in farrow-to-finish production. Hoop structures are being used to house swine in at least seven Canadian provinces. Currently, more than 400 hoop structures are used for swine finishing in Manitoba (Conner, 1994).

Practice: Rotational Grazing

Description: Intensive rotational grazing is known by many terms, including intensive-grazing management, short duration grazing, savory grazing, controlled grazing management, and voisin-grazing management (Murphy, 1998). This practice involves rotating grazing cattle (both beef and dairy) among several pasture subunits or paddocks to obtain maximum efficiency of the pasture land. Dairy cows managed under this system spend all of their time not associated with milking out on the paddocks during the grazing season and beef cattle spend all of their time out on the paddocks during the grazing season. Intensive rotational grazing is rarely, if ever, used at swine and poultry operations. Nonruminants such as swine and poultry are typically raised in confinement because of the large number of animals produced and the need for supplemental feed when they are raised on pastures.

Application and Performance: Rotational grazing is applicable to all beef and dairy operations that have sufficient land. During intensive rotational grazing, each paddock is grazed quickly (1 or 2 days) and then allowed to regrow, ungrazed, until ready for another grazing. The recovery period depends on the forage type, the forage growth rate, and the climate, and may vary from 10 to 60 days (USDA, 1997). This practice is labor- and land-intensive as cows must be moved daily to new paddocks. All paddocks used in this system require fencing and a sufficient water supply. Many operations using intensive rotational grazing move their fencing from one paddock to another and have a water system (i.e., pump and tank) installed in each predefined paddock area.

The number of required paddocks is determined by the grazing and recovery periods for the forage. For example, if a pasture-type paddock is grazed for 1 day and recovers for 21 days, 22 paddocks are needed (USDA, 1997). The total amount of land required depends on a number of factors including the dry matter content of the pasture forage, use of supplemental feed, and the number of head requiring grazing. Generally, this averages out to one or two head per acre of pasture land for both beef and dairy cattle (Hannawale, 2000). Successful intensive rotational grazing, however, requires thorough planning and constant monitoring. All paddocks should be monitored once a week. High-producing milk cows (those producing over 80 lbs/day) need a large forage allowance to maintain a high level of intake. Therefore, they need to graze in pastures that have sufficient available forage or be fed stored feed (USDA, 1997). It is also expected that beef cattle would need sufficient forage or stored feed to achieve expected weight gains.

The climate in many regions is not suitable for year round rotational grazing. Operations in these regions must maintain barns or dry lots for the cows when they are not being grazed or outwinter their cows. Outwintering is the practice of managing cows outside during the winter months. This is not a common practice because farmers must provide additional feed as cows expend more energy outside in the winter, provide windbreaks for cattle, conduct more frequent and diligent health checks on the cows, and keep the cows clean and dry so that they can stay warm (CIAS, 2000).

There are two basic management approaches to outwintering: rotation through paddocks and sacrifice paddocks. Some farms use a combination of these practices to manage their cows during the winter. During winter months, farmers may rotate cattle, hay, and round bale feeders throughout the paddocks. The main differences between this approach and standard rotational grazing practices are that the cows are not rotated as often and supplemental feed is provided to the animals. Deep snow, however, can cause problems for farmers rotating their animals in the winter because it limits the mobility of round bale feeders. The outwintering practice of "sacrifice paddocks" consists of managing animals in one pasture during the entire winter. There are several disadvantages and advantages associated with this practice. If the paddock surface is not frozen during the entire winter, compaction, plugging (tearing up of the soil), and puddling can occur. Due to the large amounts of manure deposited in these paddocks during the winter, the sacrificial paddocks must be renovated in the spring. This spring renovation may consist of dragging or scraping the paddocks to remove excess manure and then seeding to reestablish a vegetative cover. Some farmers place sacrifice paddocks strategically in areas where an undesirable plant grows or where they plan to reseed the pasture or cultivate for a crop (CIAS, 2000).

EPA conducted an analysis to estimate the manure reduction achievable with intensive rotational grazing at model beef and dairy operations (ERG, 2000a). Outwintering was not assumed to occur in this analysis. During the months that the cows from the model dairies and feedlots were assumed not to be on pasture, the amount of manure that must be managed is assumed to be equal to the amount produced at equal size confined dairy operations and beef feedlots. Table 8-5 presents the estimated range of months that intensive rotational grazing systems might be used at dairy farms and beef feedlots located in each of the five geographical regions included in this analysis.

It is estimated that approximately 15 percent of the manure generated by dairy cows is excreted in the milking center and 85 percent is excreted in the housing areas (i.e., barns, dry lots, pastures) (USDA NRCS, 1996). It is also estimated that 23 to 28 percent of the wastewater volume generated from a flushing dairy operation comes from the milking center and 72 to 77

Table 8-5. Amount of Time That Grazing Systems May Be Used at Dairy Farms and Beef Feedlots, by Geographic Region.

Region	Annual Use of Grazing Systems (months)
Pacific	3–12
Central	3–12
Midwest	3– 6
Mid-Atlantic	3– 9
South	9–12

percent (median of 75 percent) of the wastewater comes from flushing the barns (USEPA, 2000). All wastewater from a hose-and-scrape dairy system is generated at the milking center. Thus, dairies using intensive rotational grazing systems would manage 85 percent less solid manure and approximately 75 percent less wastewater (for flushing operations) than confined systems, during the months that the cows are on pasture.

All of the manure generated at beef feedlots using intensive rotational grazing systems would be excreted on the pasture during the months that the cows are grazing. No significant amounts of process wastewater are generated at beef feedlots. Thus, beef feedlots using intensive rotational grazing systems would manage 100 percent less solid waste during the months that the cows are on pasture.

Two model farm sizes were analyzed for dairy farms, assuming an average size of 454 (for medium-sized dairies) and 1,419 milking cows (for large-sized dairies). Both of these size groups are significantly larger than the 100 head or smaller operations expected to use intensive rotational grazing systems. Therefore, the specific model farm calculations are viewed as significantly overestimating the amount of collected manure and wastewater that could be reduced at typical intensive rotational grazing operations versus confined operations. For this reason, estimates on collected manure and wastewater reduction are presented on a per-head basis and model farm basis for the two dairy farm types (flushing, hose and scrape) included in EPA's ELG analysis for each of the five geographical regions.

Three model farm sizes were analyzed for beef feedlots, assuming an average size of 844 (for medium-sized feedlots), 2,628 (for large-sized feedlots), and 43,805 beef slaughter steer (for very large feedlots). Due to the slow weight gain associated with grazing operations for beef cattle and required number of pasture acres, beef feedlots of these sizes are not expected to use intensive rotational grazing systems. However, estimates on collected manure reductions are presented on a per-head basis and model farm basis for the three sizes of beef feedlots included in EPA's ELG analysis for each of the five geographical regions.

Table 8-6 presents the expected reduction in collected manure and wastewater for flush and hose-and-scrape dairy operations, by head, and by region. Table 8-7 presents the expected reduction in collected manure and wastewater for dairy operations by model farm, and by region. Table 8-8 presents the expected reduction in collected manure for beef feedlots, by head, and by region.

Table 8-9 presents the expected reduction in collected manure for beef feedlots by model farm, and by region.

Table 8-6. Expected Reduction in Collected Solid Manure and Wastewater at Dairies Using Intensive Rotational Grazing, per Head.

Farm Type	Region	Manure Reduction (lb/yr/head)	Wastewater Reduction (gal/yr/head)
Flush	Pacific	10,200–41,500	9,000–36,500
	Central	10,200–41,500	9,000–36,500
	Midwest	10,200–20,500	9,000–18,000
	Mid-Atlantic	10,200–30,700	9,000–27,000
	South	30,700–41,500	27,000–36,500
Hose and Scrape	Pacific	10,200–41,500	0
	Central	10,200–41,500	0
	Midwest	10,200–20,500	0
	Mid-Atlantic	10,200–30,700	0
	South	30,700–41,500	0

Table 8-7. Expected Reduction in Collected Solid Manure and Wastewater at Dairies Using Intensive Rotational Grazing, per Model Farm.

Farm Size (head)	Farm Type	Region	Manure Reduction (lb/yr/farm)	Wastewater Reduction (gal/yr/farm)
454	Flush	Pacific	4,630,800– 18,841,000	4,086,000– 16,571,000
		Central	4,630,800– 18,841,000	4,086,000– 16,571,000
		Midwest	4,630,800– 9,307,000	4,086,000– 8,172,000
		Mid-Atlantic	4,630,800– 13,937,800	4,086,000– 12,258,000
		South	13,937,800– 18,841,000	12,258,000–16,571,000
454	Hose & Scrape	Pacific	4,630,800– 18,841,000	0
		Central	4,630,800– 18,841,000	0
		Midwest	4,630,800– 9,307,000	0
		Mid-Atlantic	4,630,800– 13,937,800	0
		South	13,937,800– 18,841,000	0
1419	Flush	Pacific	14,473,800– 58,888,500	12,771,000– 51,793,500
		Central	14,473,800– 58,888,500	12,771,000– 51,793,500
		Midwest	14,473,800– 29,089,500	12,771,000– 25,542,000
		Mid-Atlantic	14,473,800– 43,563,300	12,771,000– 38,313,000
		South	43,563,300– 58,888,500	38,313,000– 51,793,500
1419	Hose and Scrape	Pacific	14,473,800– 58,888,500	0
		Central	14,473,800– 58,888,500	0
		Midwest	14,473,800– 29,089,500	0
		Mid-Atlantic	14,473,800– 43,563,300	0
		South	43,563,300– 58,888,500	0

Table 8-8. Expected Reduction in Collected Solid Manure at Beef Feedlots Using Intensive Rotational Grazing, per Head.

Region	Manure Reduction (lb/yr/head)
Pacific	5,040–20,167
Central	5,040–20,167
Midwest	5,040–10,080
Mid-Atlantic	5,040–15,120
South	15,120–20,167

Table 8-9. Expected Reduction in Collected Solid Manure at Beef Feedlots Using Intensive Rotational Grazing, per Model Farm.

Farm Size (head)	Region	Manure Reduction (lb/yr/farm)
844	Pacific	4,255,170–17,020,680
	Central	4,255,170–17,020,680
	Midwest	4,255,170–8,510,340
	Mid-Atlantic	4,255,170–12,765,510
	South	12,765,510–17,020,680
2628	Pacific	13,249,500–52,998,000
	Central	13,249,500–52,998,000
	Midwest	13,249,500–26,499,000
	Mid-Atlantic	13,249,500–39,748,500
	South	39,748,500–52,998,000
43805	Pacific	220,849,640–883,398,550
	Central	220,849,640–883,398,550
	Midwest	220,849,640–441,699,280
	Mid-Atlantic	220,849,640–662,548,910
	South	662,548,910–883,398,550

Advantages and Limitations: Compared with traditional grazing, intensive rotational grazing has been identified as environmentally friendly and, when managed correctly, is often considered better than conventional or continuous grazing. The benefits associated with intensive rotational grazing versus conventional grazing include:

- Higher live-weight gain per acre. Intensive rotational grazing systems result in high stocking density, which increases competition for feed between animals, forcing them to spend more time eating and less time wandering (AAC, 2000).
- Higher net economic return. Dairy farmers using pasture as a feed source will produce more feed value with intensive rotational grazing than with continuous grazing (CIAS,

2000). Competition also forces animals to be less selective when grazing. They will eat species of plants that they would ignore in other grazing systems. This reduces less desirable plant species in the pasture and produces a better economic return (AAC, 2000).

- Better land. Pastureland used in rotational grazing is often better maintained than typical pastureland. Intensive rotational grazing encourages grass growth and development of healthy sod, which in turn reduces erosion. Intensive rotational grazing in shoreline areas may help stabilize stream banks and could be used to maintain and improve riparian habitats (PPRC, 1996).

- Less manure handling. In continuous grazing systems, pastures require frequent maintenance to break up large clumps of manure. In a good rotational system, however, manure is more evenly distributed and will break up and disappear faster. Rotational grazing systems may still require manure maintenance near watering areas and paths to and from the paddock areas (Emmicx, 2000).

Grazing systems are not directly comparable with confined feeding operations, as one system can not readily switch to the other. However, assuming all things are equal, intensive rotational grazing systems might have some advantages over confined feeding operations. They are:

- Reduced cost. Pasture stocking systems are typically less expensive to invest in than livestock facilities and farm equipment required to harvest crops. Feeding costs may also be lowered.

- Improved cow health. Dairy farmers practicing intensive rotational grazing typically have a lower cull rate than confined dairy farmers, because the cows have less hoof damage, and they are more closely observed by the farmer as they are moved from one paddock to another (USDA, 1997).

- Less manure handling. Intensive rotational grazing operations have less recoverable solid manure to manage than confined operations.

- Better rate of return. Research indicates that grazing systems are more economically flexible than the confinement systems. For example, farmers investing in a well-planned grazing operation will likely be able to recover most of their investment in assets if they leave farming in a few years. But farmers investing from scratch in a confinement operation would at best recover half their investments if they decide to leave farming (CIAS, 2000).

The disadvantages associated with intensive rotational grazing compared with either conventional grazing or confined dairy operations include

- Limited applicability. Implementation of intensive rotational grazing systems is dependent upon available acreage, herd size, land resources (i.e., tillable versus steep or rocky), water availability, proximity of pasture area to milking center (for dairy operations), and feed storage capabilities. Typical confined dairy systems and beef feedlots are often not designed to allow cows easy access to the available cropland or pastureland. Large distances between the milking center and pastureland will increase the dairy cow's expended energy and, therefore, increase forage demands.

In most of the country, limited growing seasons prevent many operations from implementing a year-round intensive rotational grazing system. Southern states such as Florida can place cows on pasture 12 months of the year, but the extreme heat presents other problems for cows exposed to the elements. Grazing operations in southern states typically install shade structures and increase water availability to cows, which in turn increases the costs and labor associated with intensive rotational grazing systems. Because most operations cannot provide year-round grazing, they still must maintain barns and dry lot areas for their cows when they are not grazing, and operations often prefer not to have to maintain two management systems.

- <u>Reduced milk production levels</u>. Studies indicate that dairy farmers using intensive rotational grazing have a lower milk production average than confined dairy farms (CIAS, 2000). Lower milk production can offset the benefit of lower feed costs, especially if rations are not properly balanced once pasture becomes the primary feed source during warm months.
- <u>Reduced weight gain</u>. Beef cattle managed in an intensive rotational grazing system would gain less weight per day than beef cattle managed on a feedlot unless they were supplied with extensive supplemental feed.
- <u>Increased likelihood of infectious diseases</u>. Some infectious diseases are more likely to occur in pastured animals due to direct or indirect transmission from wild animals or the presence of an infective organism in pasture soil or water (Hutchinson, 1998).
- <u>Limited flexibility</u>. Intensive rotational grazing systems have limited flexibility in planning how many animals can be pastured in any one paddock. Available forage in a paddock can vary from one cycle to another, because of weather and other conditions that affect forage growth rates. As a result, a paddock that was sized for a certain number of cows under adequate rainfall conditions will not be able to accommodate the same number of cows under drought conditions (USDA, 1997).

Operational Factors: As mentioned earlier, most dairy operations and beef feedlots cannot maintain year-round intensive rotational grazing systems. These systems are typically operated between 3 and 9 months of the year–with 12 months most likely in the southern states. Although outwintering is a possibility for year round grazing in more northern states, it is not a common practice.

Demonstration Status: Due to the labor, fencing, water, and land requirements of intensive rotational grazing, typically only small dairy operations (those with less than 100 head) use this practice (Hannawale, 2000; USDA NRCS, 2000; CIAS, 2000). Few beef feedlots practice intensive rotational grazing. Climate and associated growing seasons make it very difficult for operations to use an intensive rotational grazing system throughout the entire year.

Practice: Pasture-Based Systems at Swine Operations

Description: There are three main types of outdoor management systems at swine operations: pasture, open lots, and buildings with outside access. In pasture systems, crops are grown and the animals are allowed to forage for their own food. Open lots are generally nonvegetative areas where the animals are allowed to roam. These open lots are typically available to animals that are housed in buildings with outside access. The focus of this discussion is the pasture systems.

Application and Performance: This practice is applicable to any swine operation that has sufficient land. However, the practicality of the practice decreases with operation size. Wheaton and Rea (1999) found that the use of a good pasture containing such crops as alfalfa, clover, and grasses can support about eight to ten sows. Stocking rates, however, will depend upon soil fertility, quality of pasture, and time of year. The recommended stocking rates are (Wheaton and Rea, 1999):

- Sows with litters — 6 to 8 head per acre
- Pigs from weaning to 100 pounds — 15 to 30 head per acre
- Pigs from 100 pounds to market — 10 to 20 head per acre
- Gestating sows — 8 to 12 head per acre

Wheaton and Rea (1999) also found that pastured swine must receive 2 to 3 pounds of grain daily plus minerals and salt for proper weight gain. Adequate shade and water must also be provided to pastured swine. Swine can be very tough on pastures and soil. Therefore, it is recommended that producers rotate swine after each season and use the pasture for other animals or harvest hay for about 2 years before using it again for swine (Wheaton and Rea, 1999). All the waste produced by the animals while they are pastured is incorporated into the sod, and therefore requires minimal waste disposal.

Advantages and Limitations: A pasture-based system offers a number of advantages and disadvantages over confinement housing to swine producers. The advantages include (Wheaton and Rea, 1999)

- Lower feed costs on good pasture
- Exercise and nutrients for breeding sows
- Lower capital investment per production unit
- Good use of land not suitable for machine harvest
- Better isolation and disease control
- Decreased waste management handling
- Decreased cannibalism

The disadvantages include (Wheaton and Rea, 1999)

- Increased labor for animal handling, feeding, and watering
- Increased risk of internal parasites
- Increase labor for farrowing
- Increase animal production time to reach desired market weight
- Lack of environmental controls

Operational Factors: The increased labor costs associated with pasture-based swine operations are partially offset by decreased waste handling costs and reduced feed costs.

Demonstration Status: Data from the USDA's APHIS - Veterinary Service indicate pasture-based systems are used at 7.6 percent of farrowing operations, 1.5 percent of nurseries, and 6.7 percent of finishing operations (USDA APHIS, 1995). The percentage of pigs raised on such operations is about five times less than the number of operations, indicating these operations are generally smaller than other types of swine operations. NAHMS confirmed this with additional analysis of the *Swine '95* data, and indicated 7 to 8 percent of swine farms with fewer than 750 total head use pasture systems, but less than 1 percent of swine operations larger than 750 head use pasture systems (USDA NAHMS, 1999).

Practice: Pasture-Based Systems at Poultry Operations

Description: Pastured poultry refers to broilers, layers, and turkeys that are raised on pasture and feed. There are three basic methods for raising poultry on pasture: pasture pens, free range, and day range (Lee, 2000). Pasture pens are bottomless pens that hold layers, broilers, or turkeys, and are moved daily or as needed to give the poultry fresh pasture. This is the most commonly used pasture poultry method at present. To accommodate layers, nest boxes are fixed to the side of the pen. Approximately 30 to 40 hens can be housed in one typical pasture pen. Free range generally means a fenced pasture surrounding the barn or poultry shelter, and day range is similar to free range except that the birds are sheltered at night from predators and weather.

Application and Performance: The use of pasture pens has been documented at operations with 1,000 birds but is believed to be used most commonly at operations with fewer than 1,000 birds. Lee (2000) also indicates that pastured poultry operations require up to twice the amount of feed as confined poultry does to achieve the same weight gain and/or production goal. All wastes produced while the birds are on pasture is incorporated into the sod, and therefore results in minimal waste requiring disposal.

Advantages and Limitations: Some of the advantages associated with pastured poultry versus confinement housing are:

- Pasture pens are easy and inexpensive to build
- Controlled moves will harvest grass and help spread manure uniformly across the field

- Perimeter fencing is not required
- Diseases associated with confinement housing may be less likely to occur
- Waste management handling is reduced
- Pasture-raised birds may have a higher market value (Lee, 2000)

The limitations associated with pastured poultry include the following:

- The small pens hold relatively few poultry, compared with their cost
- Pens can trap heat, leading to heat stress
- The roof height of the pens is too low for turkeys to stretch and raise their heads to full height
- Pens may be difficult to move
- Pens offer only minimal protection from weather
- Birds often have to bed down at night in manure-soaked grass (Lee, 2000)

Operational Factors: Pasture-based poultry operations require increased labor for animal handling, feeding, and watering (Lee, 2000). This increased labor is partially offset by a decrease in waste management.

Demonstration Status: No data could be found to indicate the number of pasture-based poultry operations. However, the use of pasture pens is rarely observed at operations with more than 1,000 birds. Thus few if any pastured poultry operations confine sufficient numbers of birds to be defined as CAFOs on the basis of operation size.

8.2 Manure/Waste Handling Storage and Treatment Technologies

Manure is often used as a nutrient source and soil amendment, and can be used effectively by itself or along with other nutrient sources such as commercial fertilizer. In some cases surplus manure can be treated, processed, or repackaged to increase its value as a nutrient resource (such as compost, pelletized litter, or a fertilizer blend). When manure is generated in excess of what can be locally utilized either as a nutrient source or some other alternative use, it is often treated as a waste. EPA believes manure is most effectively used as a resource, and the use of the term waste in the following sections is not meant to imply to the contrary.

The term "waste" as it relates to AFOs includes manure, bedding material, spilt or waste feed, animal carcasses, and other by products. There are a variety of methods for handling, storing, and treating waste. Waste may be handled both in a solid form and through the use of water. As stated in earlier chapters, some facilities use water to move the waste away from the animals and then separate the solids from the liquids prior to storage, treatment, and disposal. Water may also be used for cleaning and disinfection, especially at dairies and egg-producing facilities. Storage and treatment of waste is done in the both the solid and liquid/slurry forms.

8.2.1 Waste Handling Technologies and Practices

Different practices are used to handle or move liquid and solid wastes, and the choice of practices depends on the type of housing configuration. Housing configurations include total confinement, which is the most common and used almost exclusively in the poultry industry and at larger swine operations, open buildings with or without outside access, and lots or pastures with a hut or with no buildings.

Practice: Handling of Waste in Solid Form

Description: The use of hoop houses for swine and high-rise hog houses to handle manure in a dry form was discussed in section 8.1. In facilities with open lots, manure accumulates on the ground as a solid that can be diluted by rainfall (mostly for beef and dairy, swine and poultry are mostly totally confined) or by spillage from watering areas. Whether the lot is paved, partially paved, or unpaved, manure is typically handled as a solid or slurry and is scraped with tractor scrapers or front-end loaders and stored in a pile (see Figure 8-2). There are several options for separating solid manure from the animals at confinement facilities. Solid, unslatted floors, both paved and unpaved, can be hand-scraped or scraped with a tractor or front-end loader into a pile, pit, or other storage facility. Sloped floors further aid in manure collection as animal traffic works the manure downslope. Other facilities use uncovered alley or gutter systems combined with hand scraping, automatic scraping, or sloped floors to collect manure. Scraped manure from underslat gutters, alleys, or shallow pits can be held temporarily in a pit or a deep collection gutter at one end of the building, from which it can be applied to the land or transferred to a more permanent storage structure.

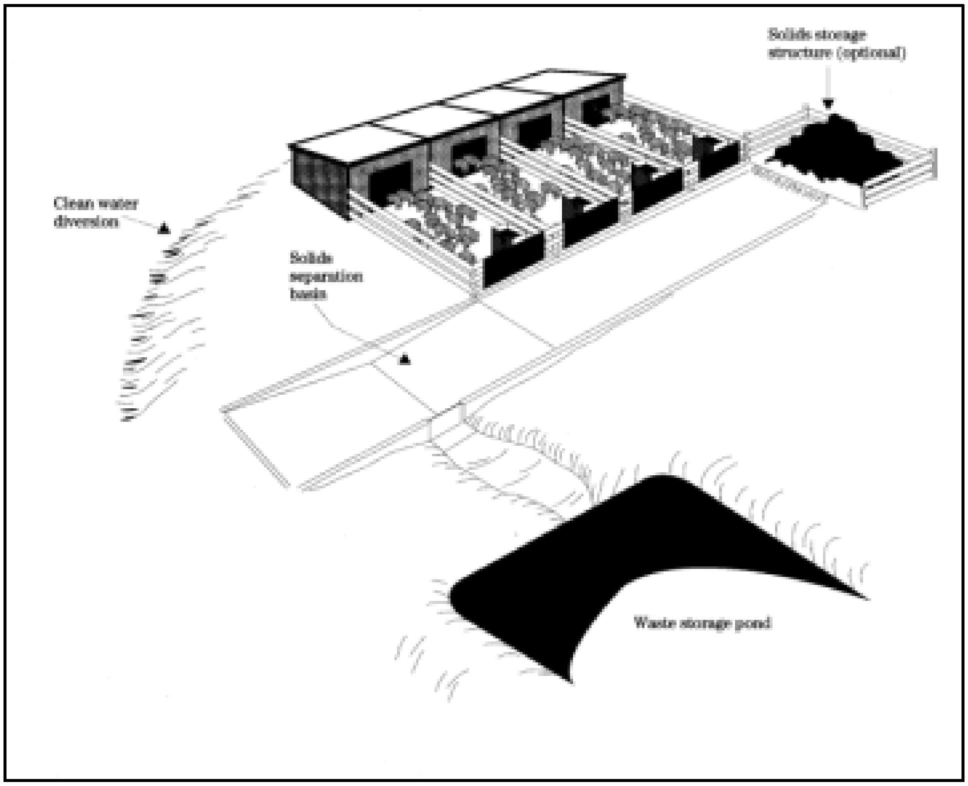

Figure 8-2. Manure scraped and handled as a solid on a paved lot operation (USDA NRCS, 1996).

Application and Performance: Solid systems are best suited for open lot facilities, especially in areas that have a dry climate because exposed manure is less likely to be diluted by excess rainfall. The choice of solid or liquid handling systems, however, has been historically based on operator preference with respect to capital investment, labor requirements, and available equipment and facilities.

Advantages and Limitations: Solid handling systems offer both advantages and disadvantages to facility operators. For instance, solid systems use equipment that is already present at the facility, such as tractors and front-end loaders. Tractors and front-end loaders are flexible, have fewer mechanical problems, are less subject to corrosion, and work well on frozen manure, but they require more labor than automatic scrapers. Solid systems are not as automated as liquid systems; although they involve little or no capital investment and require less maintenance, they require much more labor than mechanical scraper systems or flushing systems. An advantage to solid systems is that the volume of manure handled is much less than the volume associated with liquid systems, which translates into smaller storage facility requirements. Bedding can be used without concern for pumping or agitating equipment problems (which are a concern for liquid handling systems).

Operational Factors: The extent of paving on an open lot determines the care with which manure is removed. Unpaved lots develop an impervious layer from bacterial activity and hoof action, and this layer protects against soil loss and percolation of liquids. Also, scraping of unpaved surfaces incorporates sand and soil into the manure, which can cause problems with storage or treatment of the manure. If scraped manure is to be stacked, it may be necessary to add an appreciable amount of bedding to attain a more solid consistency.

Demonstration Status: Solid handling systems are fairly common at smaller swine operations. According to *Swine '95* (USDA APHIS, 1996a), removal of manure by hand is used most often in all types of operations (farrowing 38.2 percent, nursery 29.9 percent, and grow-finish 27.2 percent). Mechanical scrapers and tractors are also used for solids handling (farrowing 12.0 percent, nursery 17.6 percent, and grow-finish 24.9 percent).

Poultry waste is mostly handled as a dry litter, the exception being layer operations, particularly in the South Region (USDA NAHMS, 2000a).

Manure is often handled in solid form at smaller dairy farms. According to *Dairy '96* (USDA APHIS, 1996a), gutter cleaners are used most often to remove manure from dairy cow housing areas (63.2 percent). Mechanical scrapers or tractors are frequently used to clean alleys (57.7 percent). A number of dairies store manure in solid form; 79.2 percent of dairies with fewer than 100 cows and 59.5 percent of dairies with 200 or more cows are reported to use some form of solid waste storage (USDA APHIS, 1996b).

Scraping is the most common method of collecting solid and semisolid manure from beef barns and open lots. Solids can be moved with a tractor scraper and front-end loader. Mechanical scrapers are typically used in the pit under barns with slotted floors. Scraping is common for medium and large feedlots.

Practice: Teardrop, V- and Y-Shaped Pits With Scraper

Description: Confinement facilities have several manure collection options for separating manure liquids from manure solids. Several underfloor gutter systems that are applicable only to swine will be discussed. No comparable manure collection systems that separate liquids and solids are known for other animal species.

The reason for separating swine manure into solids and liquids is to concentrate pollutants and nutrients. Kroodsma (1985) installed a plastic 0.78 mm filter net under the floor of a pig house in which eight pigs were fed by wet feeders so that no excess water fell into the manure. Solids fell onto the screen and liquids passed through. The results showed that the relatively undisturbed feces contained about 80 percent of the BOD, COD, total solids (TS), P, calcium Ca, magnesium (Mg), and copper (Cu). Sixty per cent of the total TKN and forty percent of the K were also retained in the filter net. Thus, if solids can be recovered relatively intact, parameters such as nutrients will be concentrated.

Two gutter configurations that may be useful for swine operations are Y-shaped and V-shaped gutters under slatted floors (Tengman, et al., n.d.). The sloping sides of the gutters facilitate retention of solids and allow liquids to drain to the center collection area. Scrapers pull the solids to one end of the barn for solids handling, while liquids flow with gravity in the opposite direction for management in a liquid manure system.

V-shaped gutters are easier to build than Y-shaped gutters and may be easier to clean. Manure movement in V-shaped gutters is not substantially different than in Y-shaped gutters. The sideslope of Y- or V-shaped gutters should be 1:1 for farrowing operations and 3/4:1 for nurseries. A slope of 1:240 to 1:480 is recommended for the liquid gutter (Tengman, et al., n.d.).

Manure that is scraped from underslat gutters, alleys, or shallow pits can be held temporarily in a pit or a deep collection gutter at one end of the building, from which it can be applied to the land or transferred to a more permanent storage structure.

Application and Performance: The choice of a manure-handling system is based primarily on operator preference with respect to capital investment, labor requirements, and available equipment and facilities. Demonstration of the economic viability or the value of concentrating nutrients using the Y-shaped and V-shaped gutter is apparently lacking. No performance data was found from full-scale demonstration of the segregation of constituents including pathogens, metals, growth hormones, and antibiotics.

Advantages and Limitations: The advantage in using a Y-shaped or V-shaped scrape collection system would be the concentration of nutrients in the solids. Nutrients concentrated in solid form are cheaper to haul than in slurry form because water, which would increase the weight and volume, is not added. Disadvantages include reduced air quality in hog buildings over manure solids smeared on the collection slope, repair of cable scrapers in small spaces under slatted floors with hogs present, the need for the operator to manage both a compost or solids stacking operation with solids handling equipment and a liquid storage and application system with liquid handling equipment.

Operational Factors: Climate, temperature, and rainfall generally do not affect scraper systems in hog barns. If scraped manure solids are to be stacked or composted, it may be necessary to add an appreciable amount of bedding to attain a more solid consistency.

Demonstration Status: Underslat manure scrape and gutter systems to direct manure liquids and solids to different handling systems have been developed, but they are not commonly used.

Practice: Handling of Waste in Liquid Form

Description: Liquid handling systems are the alternative to scraping and hauling manure. They are especially common in confinement housing operations because it is easier to install automated systems inside new or existing structures and it is more difficult to maneuver tractors or front-end loaders for scraping in small pens and tight corners. Excreted manure can be collected in shallow, narrow, open gutters or alleys, or it can collect under slats in gutters or pits for periodic flushing to a more permanent storage or treatment facility. The manure can also be directly applied to land without extended storage or treatment.

Slotted floors are an efficient method for removing manure from animal areas. Floors tend to be typically partially slotted over a pit or gutter. Feeding and resting areas are located on solid floors, and watering areas are placed over slotted floors. Manure is worked through the slats by hoof action and is stored beneath the slats until it is pumped or flushed to a lagoon. Fresh water can be used for flushing or water from a secondary lagoon can be recycled as flush water. An example of a slotted floor system is shown in Figure 8-3.

Application and Performance: Liquid manure systems are most frequently used for large animal facilities, where the automation of waste management systems is very important. They may also be preferred where water is abundant or when rainfall on open lots causes considerable dilution of manure solids. Liquid systems are especially appropriate when spray irrigation of nutrient-laden waters is the preferred method for fertilizing and watering crops.

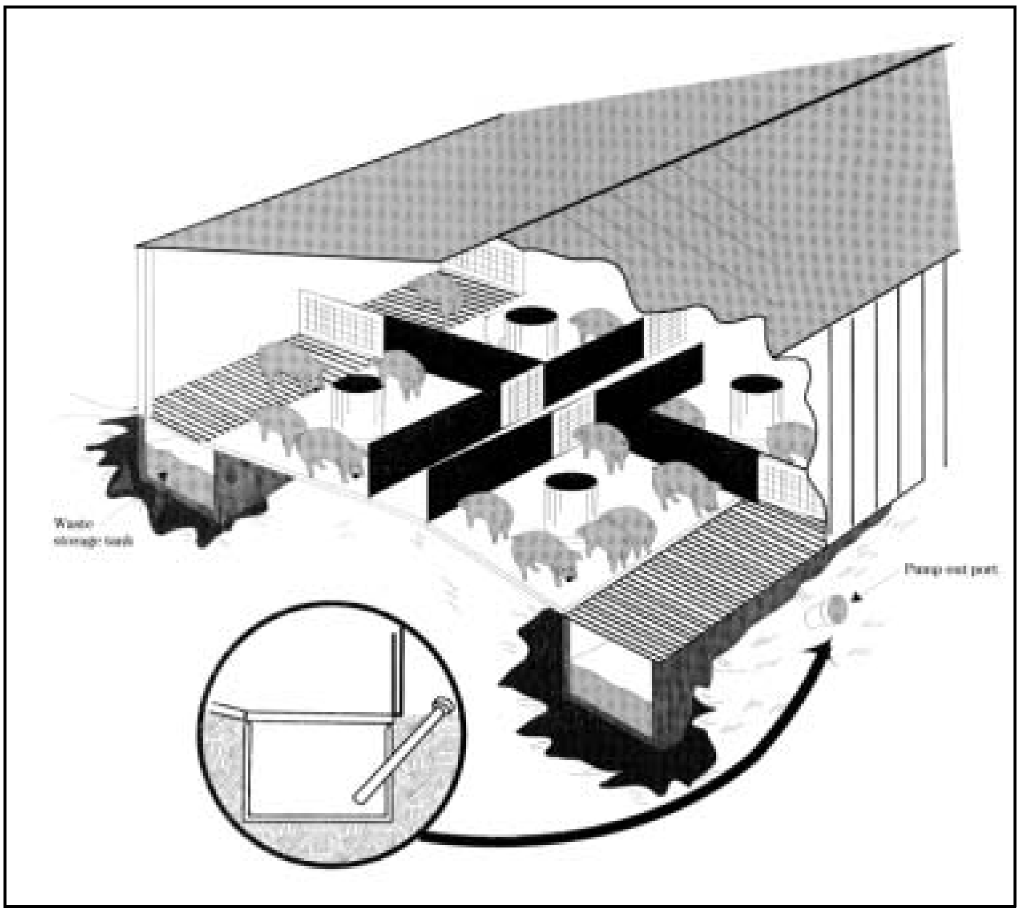

Figure 8-3. Fed hogs in confined area with concrete floor and tank storage liquid manure handling (USDA NRCS, 1996).

Advantages and Limitations: Flushing systems with liquid manure handling are less labor-intensive and more automated than solid handling systems, but the volume of manure and water to be stored, treated, and disposed of is greater. Flushing systems require large volumes of water to be pumped and stored in a sump until discharged by gravity flow or pumped to a lagoon. Consequently, where water is a valuable commodity, liquid systems might not be economical. This limitation can be offset by recycling flush water from treatment lagoons. Equipment needed for liquid systems, including sumps, pumps, agitators, choppers, and sprayers, brings with it high capital, operating, and maintenance costs, although savings may be seen in decreased labor costs. Manure consistency is very important in liquid handling systems because the equipment can be damaged by fibrous material (bedding), sand, or other foreign materials. Periodic cleanout of solids is necessary to maintain the capacity and proper functioning of storage structures and handling equipment.

Operational Factors: Slats can be made of wood, concrete, steel, aluminum, or plastic. Concrete is the most sturdy material, is the least corrodible, and handles the weight of larger animals, but it requires extra supports and the initial costs are higher than the costs of other materials. Wood is the least expensive material, but it can be chipped by the animals and needs to be replaced at least every 2 to 4 years. Plain steel and aluminum slats are subject to corrosion, but they can be galvanized or coated with paint or plastic to extend their life. Plastic slats, metal grates, expanded metal mesh, and stainless steel slotted planks are appropriate for swine farrowing and nursery operations that house smaller pigs. Openings between slats should be greater than 3/4 inch, up to 1 3/4 inches for swine operations.

Demonstration Status: The *Swine '95* report (USDA APHIS, 1996a) demonstrates that liquid systems, although not the most common type on a facility-by-facility basis, are still used fairly frequently. Flushing under slats accounts for 5.3 percent of farrowing, 9.4 percent of nursery, and 2.4 percent of grow-finish operations, whereas flushing with open gutter systems accounts for 3.0, 2.1, and 3.4 percent of each operation type, respectively. Liquid handling systems are becoming increasingly popular as larger operations become more prevalent, necessitating automated systems for manure handling.

Poultry waste is mostly handled as a dry litter, the exception being layer operations, particularly those in the South Region. Approximately 40 percent of the laying operations in the South use a flush system with a lagoon (USDA NAHMS, 2000).

Dairy '96 (USDA APHIS, 1996a) reports that a small number of dairy farms, 2.8 percent, use water to remove manure from alleys. However, over 90 percent of operations with 200 or more cows are reported to use liquid manure storage systems (USDA APHIS, 1996b). According to the NAHMS survey results (Garber, 1999), approximately 50 percent of all facilities with greater than 500 mature dairy cows employ flushing as a means of cleaning the housing area.

A flushing system dilutes manure from beef feedlots with water to allow for automated handling. The system uses a large volume of water to flush manure down a sloped gutter to storage, where the liquid waste can be transferred to a storage lagoon or basin. This system is not common for large beef feedlots; however, this type of system is widely used at veal operations (Loudon, 1985). Based on EPA site visits, about 67 percent of veal operations flush manure to liquid lagoon storage systems.

Practice: Berms and Storm Water Diversions

Description: "Clean" storm water runoff from land surrounding livestock facilities can be diverted from barns, open animal concentration areas, and waste storage or treatment facilities to prevent mixing with wastewater. This is accomplished through earthen perimeter controls and roof runoff management techniques.

Earthen perimeter controls usually consist of a berm, dike, or channel constructed along the perimeter of a site. Simply defined, an earthen perimeter control is a ridge of compacted soil, often accompanied by a ditch or swale with a vegetated lining, located at the top or base of a sloping area. Depending on their location and the topography of the landscape, earthen perimeter controls can achieve one of three main goals: preventing surface runoff from entering a site, diverting manure-laden runoff created on site to off-site waste trapping devices, and intercepting clean storm water runoff and transporting it away from lagoons or belowground tanks. Therefore, diversions are used to protect areas from runoff and divert water from areas where it is in excess to locations where it can be stored, used, or released. Thus, it prevents the mixing of clean storm water with manure-laden wastewater, reducing the volume of wastewater to be treated.

Roof runoff management techniques such as gutters and downspouts direct rainfall from roofs away from areas with concentrated manure. Because these devices prevent storm water from mixing with contaminated water, they also reduce the volume of wastewater to be treated.

Application and Performance: Earthen perimeter controls or diversions are applicable where it is desirable to divert flows away from barns, open animal concentration areas, and waste storage or treatment facilities. They can be erected at the top of a sloping area or in the middle of a slope to divert storm water runoff around a feeding or manure storage site. However, unvegetated, earthen channels should not be used in regions of high precipitation because of potential erosion problems.

The design capacity of a channel is calculated using Manning's equation and is based on precipitation, slope, wetted perimeter, water cross-sectional area, and surface roughness. Water velocity is also a consideration in designing diversions to minimize erosion. Other types of diversions that can be used for runoff control include grassed waterways, which are natural or constructed channels that provide stable runoff conveyance, and lined waterways or outlets, which are lined channels or outlets reinforced with erosion-resistant linings of concrete, stone, or other permanent materials to provide additional stability.

Advantages and Limitations: When properly placed and maintained, earthen perimeter controls are effective for controlling the velocity and direction of storm water runoff. Used by themselves, they do not have any ability to remove pollutants and thus must be used in combination with an appropriate sediment or waste trapping device at the outfall of the diversion channel. With these diversion techniques, storm water runoff is prevented from mixing with contaminated manure-laden wastewater and thus the volume of water for treatment is decreased; however, the concentrated runoff in the channel or ditch has increased erosion potential. To such erosion, diversion dikes must be directed to sediment trapping devices where erosion sediment can settle out of the runoff before being discharged. In addition, if a diversion dike crosses a vehicle roadway or entrance, its effectiveness may be reduced. Wherever possible, diversion dikes should be designed to avoid crossing vehicle pathways.

Operational Factors: The siting of earthen perimeter controls depends on the topography of the area surrounding a specific site. When determining the appropriate size and design of these diversion channels, the shape of the surrounding landscape and drainage patterns should be considered. Also, the amount of runoff to be diverted, the velocity of runoff in the diversion, and the erodibility of soils on the slope and within the diversion channel or swale are essential design considerations.

Both diversion channels and roof management devices must be maintained to remain effective. If vegetation is allowed to grow in diversions, the roughness increases and the channel velocity decreases which can cause channel overflow. Therefore, vegetation should be periodically mowed. In addition, the dike should be maintained at the original height, and any decrease in height due to settling or erosion should be remedied.

Roof management devices such as gutters and downspouts must be cleaned and inspected regularly to prevent clogging and to ensure its effectiveness.

Demonstration Status: The use of earthen perimeter techniques such as berms, diversions, and channels and the use of roof management techniques to divert storm water away from barns, open animal concentration areas, and waste storage or treatment facilities are well-accepted practices that prevent clean wastewater from mixing with manure-laden wastewater, thus reducing the volume of wastewater to be treated.

8.2.2 Waste Storage Technologies and Practices

The USDA NRCS recommends that storage structures be designed to handle the volume of manure produced between emptying events. The minimum storage period is based on the timing required for environmentally safe waste utilization considering climate; crops; soil; equipment; and local, state, and federal regulations. The design storage volume for liquid manure should account for manure, wastewater, precipitation and runoff (if uncovered), and other wastes that will accumulate during the storage period, such as residual solids that are not removed when liquids are pumped. Other general considerations are inlet designs, outlets or pumping access, and safety (such as fencing, odor and gas control, reinforcement against earth movements and hydrostatic pressure, use of a cover, and amount of freeboard).

Practice: Anaerobic Lagoons

Description: Anaerobic lagoons are earthen basins that provide storage for animal wastes while decomposing and liquefying manure solids. Anaerobic processes degrade high BOD wastes into stable end products without the use of free oxygen. Anaerobic lagoons are designed based on volatile solids loading rates (VSLR). Volatile solids are the wastes that will decompose. The volume of the lagoon consists of the following (see Figure 8-4):

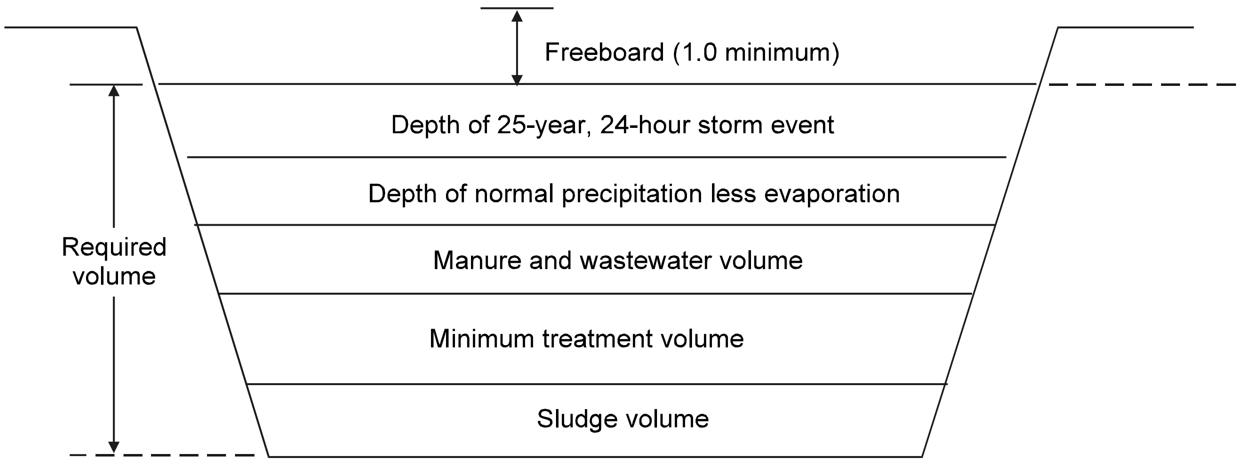

Figure 8-4. Cross section of anaerobic lagoons (USDA NRCS, 1998a)

1. Minimum Treatment Volume—The total daily volatile solids from all waste sources divided by the volatile solids loading rate for a particular region. The minimum treatment volume is based on the volatile solids loading rate, which varies with temperature and therefore with geographic location. Recommended volatile solids loading rates in the United States vary from 3 to 7 pounds per 1,000 ft^3 per day.

2. Sludge Volume—Volume of accumulated sludge between cleanouts. A fraction of the manure solids settles to the bottom of the lagoon and accumulates as sludge. The amount of sludge accumulation depends on the type and amount of animal waste.

3. Manure and Wastewater Volume—The volume of manure and wastewater transferred from feedlot operational facilities to the lagoon during the storage period. Lagoons are typically designed to store from 90 to 365 days of manure and wastewater.

4. Net Precipitation—Precipitation minus the evaporation during the storage period.

5. Design Storm—Typically a 25-year, 24-hour storm event.

6. Freeboard—A minimum of 1 foot of freeboard. Freeboard is the extra depth added to the pond as a safety factor.

7. Runoff—The runoff volume from lagoon berms. In general, lagoons should not receive runoff because runoff can shock the lagoon with an overload of volatile solids. Some runoff will enter the lagoons from the berms surrounding them.

Anaerobic lagoons should be at least 6 to 10 feet deep, although 8- to 20-foot depths are typical. Deeper lagoons require a smaller surface area, and they more thoroughly mix lagoon contents as a result of rising gas bubbles and minimize odors. Lagoons are typically constructed by excavating a pit and building berms around the perimeter. The berms are constructed with an extra 5 percent in height to allow for settling. The sides of the lagoon should be sloped with a 2:1 or 3:1 (horizontal:vertical) ratio. Lagoons can be designed as single-stage or multiple-stage (usually two stages). Two-stage lagoons require greater total volume but produce a higher quality lagoon effluent.

Lagoon covers can be used to control odor and collect biogas produced from the natural decomposition of manure. Covers are usually made of a synthetic material, and are designed to float on the surface of the lagoon. Often, because of the large size of the lagoon, the cover is constructed in multiple modules. Each module has flotation devices at the corners to help support the cover, and is tied down at the edge of the pond or lagoon. Covers typically have drains constructed in them to allow rainwater to drain through to the lagoon.

Lagoons are sometimes used in combination with a solids separator, typically for dairy waste. Solids separators help control the buildup of nondegradable material such as straw or other bedding materials. These materials can form a crust on the surface of the lagoon, which decreases its activity.

Application and Performance: Anaerobic lagoons provide effective biological treatment of animal wastes. Anaerobic lagoons can handle high pollutant loads while minimizing manure odors. Nondegradable solids settle to the bottom as sludge, which is periodically removed. The liquid is applied to cropland as fertilizer or irrigation water or is transported off site. Properly managed lagoons will have a musty odor. Anaerobic processes decompose faster than aerobic processes, providing effective treatment of wastes with high BOD, such as animal waste. Anaerobic lagoons are larger than storage ponds because additional volume is needed to provide biological treatment; however, since a constant oxygen concentration is not required, anaerobic lagoons are generally smaller than aerobic lagoons.

Lagoons reduce the concentrations of both N and P in the liquid effluent. P settles to the bottom of the lagoon and is removed with the lagoon sludge. Approximately 60 percent of the influent N is lost through volatilization to ammonia (Fulhage, 1998 Van Horn, 1999). Microbial activity converts the organic N to ammonia N. Ammonia N can be further reduced to elemental nitrogen (N_2) and released into the atmosphere. Lagoon effluent can be used for land application or flushing of animal barns, or can be transported off site. The sludge can also be applied to land provided the soil is not saturated with nutrients. Information on the reduction of BOD, pathogens, and metals in lagoons is not available. Reductions in COD, TS, volatile solids (VS), total N, P, and K are presented in Table 8-10.

Table 8-10. Anaerobic Unit Process Performance.

Anaerobic Treatment	**HRT**	**COD**	**TS**	**VS**	**TN**	**P**	**K**
	days	Percent Reduction					
Pull plug pits	4–30	—	0–30	0–30	0–20	0–20	0–15
Underfloor pit storage	30–180	—	30–40	20–30	5–20	5–15	5–15
Open top tank	30–180	—	—	—	25–30	10–20	10–20
Open pond	30–180	—	—	—	70–80	50–65	40–50
Heated digester effluent prior to storage	12–20	35–70	25–50	40–70	0	0	0
Covered first cell of two cell lagoon	30–90	70–90	75–95	80–90	25–35	50–80	30–50
One-cell lagoon	>365	70–90	75–95	75–85	60–80	50–70	30–50
Two-cell lagoon	210+	90–95	80–95	90–98	50–80	85–90	30–50
HRT=hydraulic retention time; COD=chemical oxygen demand; TS=total solids; VS=volatile solids; TN=total nitrogen; P=phosphorus; K= potassium; — =data not available.							

Source: Moser and Martin, 1999.

Advantages and Limitations: Anaerobic lagoons offer several advantages over other methods of storage and treatment. Anaerobic lagoons can handle high pollutant loads and provide a large volume for long-term storage. They stabilize manure wastes and reduce N content through biological degradation. Lagoons allow manure to be handled as a liquid, which reduces labor costs. If lagoons are located at a lower elevation than the animal barns, gravity can be used to transport the waste to the lagoon, which further reduces labor. Mild climates are most suitable for lagoons; cold weather reduces the biological activity of the microorganisms that degrade the wastes. Lagoons can experience spring and fall turnover, in which the more odorous bottom material rises to the surface. Foul odors can also result if biological activity is reduced or if there is a sudden change in temperature or pollutant loading rate.

Operational Factors: To avoid ground water and soil contamination, several factors must be considered. The lagoon should be located on soils with low to moderate permeability or on soils that can form a seal through sedimentation and biological action (USDA NRCS, 2000). Impervious barriers or liners are used to reduce seepage through the lagoon bottom and sides and are described in the following practice.

Lagoon inlets should be designed from materials that resist erosion, plugging, and freezing. Vegetation around the pond should be maintained to help stabilize embankments.

Lagoons must be properly maintained for effective treatment. The minimum treatment volume of the lagoon must be maintained. Lagoons work best when the influent flow is a steady, gradual flow rather than a large slug flow. The pH of the lagoon should be monitored. The optimum pH for lagoon treatment is about 6.5, which maximizes the activity level of the bacteria. Lime can be added to the lagoon to increase pH to this level. Also, since the rate of volatile solids decomposition is a function of temperature, the acceptable VSLR varies with climate. The loading rate should be monitored to ensure that it is appropriate to the region in which the lagoon is located.

*Demonstration Status***:** Anaerobic lagoons without covers are used at 20.9 percent of all grow-finish swine operations. Of these, swine operations with 10,000 or more head use uncovered lagoons most frequently (81.8 percent) (USDA APHIS, 1996a). Lagoons are used on egg-laying farms in warmer climates. Beef facilities typically use storage ponds rather than lagoons. NAHMS estimates that 1.1 percent of dairies with more than 200 head use anaerobic lagoons with a cover and 46.7 percent use anaerobic lagoons without a cover (USDA APHIS, 1996b). The use of lined lagoons is dependent on site-specific conditions.

Practice: Lagoon Liners

Description: Lagoon liners are impervious barriers used to reduce seepage through the lagoon bottom and sides.

Application and Performance: Soil that is at least 10 percent clay can be compacted with a sheepsfoot roller to create a suitable impervious barrier. If the soil is not at least 10 percent clay, a liner or soil amendment should be used. There are also site conditions that may require seepage reduction beyond what is provided by compacting the natural soil. These conditions may include a shallow underlying aquifer, an underlying aquifer that is ecologically important or used as a domestic water source, or highly permeable underlying bedrock or soil. There are three options available to provide additional seepage reduction. First, the soil can be mixed with bentonite or a soil dispersant and then compacted. Clay can be imported from another area and compacted along the bottom and side walls. Last, concrete or synthetic materials such as geomembranes or geosynthetic clay liners can be used.

Advantages and Limitations: Concrete and synthetic liners are usually the most expensive.

Operational Factors: The method chosen to line the lagoon depends on the type of soil, site geography and location, available materials, and economics.

Demonstration Status: The use of lined lagoons depends on site-specific conditions.

Practice: Storage Ponds

Description: Waste storage ponds are earthen basins used to store wastes temporarily including runoff, solids (e.g., manure), and wastewater. The total volume of the pond consists of the following (see Figure 8-5):

1. Sludge Volume—Volume of accumulated sludge between cleanouts. A fraction of the manure solids settles to the bottom of the pond and accumulates as sludge. The amount of sludge accumulation depends on the type and amount of animal waste. For example, solids settling or solids separation prior to the storage pond reduces the rate of sludge accumulation.

2. Manure and Wastewater Volume—The volume of manure and wastewater from feedlot operational facilities transferred to the pond during the storage period. Ponds are typically designed to store from 90 to 270 days of manure and wastewater. The percentage of solids in the influent will depend on animal type and the waste management system.

3. Runoff—The runoff from the sites for the storage period (usually the drylot area at AFOs).

4. Net Precipitation—Precipitation minus the evaporation for the storage period.

5. Design Storm—Typically a 25-year, 24-hour storm event.

6. Freeboard—A minimum of 1 foot of freeboard. Freeboard is the extra depth added to the pond as a safety factor.

Ponds are typically rectangular in shape and are constructed by excavating a pit and building berms around the perimeter. The berms are constructed with an extra 5 percent in height to allow for settling. The sides of the pond are typically sloped with a 1.5:1 or 3:1 (horizontal:vertical) ratio.

Ponds are typically used in combination with a solids separator. Solids separators help control buildup of material such as straw or other bedding materials on the surface of the pond.

Pond covers can be used to control odor and collect biogas produced from the natural degradation of manure. Covers are usually made of a synthetic material, and are designed to float on the surface of the impoundment. Often, because of the large size of the pond, the cover is constructed in multiple modules. Each module has flotation devices at the corners to help support the cover, and is tied down at the edge of the pond. Covers typically have drains constructed in them to allow rainwater to drain through to the pond.

Application and Performance: Waste storage ponds are frequently used at AFO to contain wastewater and runoff from contaminated areas. Manure, process water, and runoff are routed to these storage ponds, where the mixture is held until it can be used for irrigation or transported off site. Solids settle to the bottom as sludge, which is periodically removed. The liquid is applied to cropland as fertilizer or irrigation water, or is transported off site.

Storage ponds hold wastewater and manure and are not intended to actively treat the waste. Because they do not require additional volume for treatment, storage ponds are smaller in size than treatment lagoons.

Ponds reduce the concentrations of both N and P in the liquid effluent. P settles to the bottom of the pond and is removed with the sludge. Influent N is reduced through volatilization to ammonia. Pond effluent can be used for land application or flushing animal barns, or it can be transported off site. The sludge can also be applied to the land provided the soil is not saturated with P.

Advantages and Limitations: Storage ponds provide a large volume for long-term waste storage and allow manure to be handled as a liquid. If ponds are located at a lower elevation than the animal barns, gravity can be used to transport the waste to the pond, which minimizes labor. Although ponds are an effective means of storing waste, no treatment is provided. Because ponds are open to the air, odor can be a problem.

Operational Factors: To avoid ground water and soil contamination, several factors must be taken into consideration. Impervious barriers or liners are used to reduce seepage through the pond bottom and sides. Soil that is at least 10 percent clay can be compacted with a sheepsfoot roller to create a suitable impervious barrier. If the soil is not at least 10 percent clay, a liner or soil amendment should be used. There are also site conditions that may require seepage reduction beyond what is provided by compacting the natural soil. Conditions may include a shallow underlying aquifer, an underlying aquifer that is ecologically important or used as a domestic water source, or highly permeable underlying bedrock or soil. There are three options available to provide additional seepage reduction. First, the soil can be mixed with bentonite or a soil dispersant and then compacted. Clay can be imported from another area and compacted along the bottom and side walls. Last, concrete or synthetic materials such as geomembranes or geosynthetic clay liners can be used. Concrete and synthetic liners are usually the most expensive. The method chosen to line the pond depends on the type of soil, site geography and location, available materials, and economics.

Pond inlets should be designed from materials that resist erosion, plugging, and freezing. Vegetation around the pond should be maintained to help stabilize embankments.

*Demonstration Status***:** Ponds are a common method of waste storage for swine, beef, and dairy facilities and are used on poultry farms in warmer climates. Beef feedlots tend to use storage ponds for collection of runoff from the dry lots. EPA estimates that 50 percent of the medium-size (300–1000 head) beef feedlots in all regions and 100 percent of the large-size (>1,000 head) beef feedlots in all regions have a storage pond for runoff. NAHMS estimates 27.8 percent of dairies use earthen storage basins (USDA APHIS, 1996b). The use of lined ponds depends on site-specific conditions.

Practice: Pit Storage

Description: Manure pits are a common method for storing animal wastes. They can be located inside the building underneath slats or solid floors, or outside and separated from the building. Typical storage periods range from 5 to 12 months, after which manure is removed from the pit and transferred to a treatment system or applied to land. There are several design options for pit storage. For example, shallow pits under slats provide temporary storage and require more frequent manure removal to longer-term storage or for land application. Pit recharge systems, which are common in the Midwest, involve regularly draining the pit contents to a lagoon and recharging the pit with fresh or recycled water. The regular dissolution of solids keeps the pits free of excessive buildup while providing temporary storage for manure. Pit recharge systems typically have level floors with an average depth of 12 inches of recharge water, 12 inches allowed for waste accumulation, and 12 inches of air space between the pit surface and the slatted floor.

Application and Performance: Because agitating and pumping equipment does not handle solid or fibrous materials well, manure with greater than 15 percent solids will require dilution. Chopper-type agitators may be needed to break up bedding or other fibrous materials that might be present in the pit.

Advantages and Limitations: Below-floor storage systems provide ease of collection and minimize volume (1.2 dilution versus 3.0 dilution for lagoon storage) while maximizing fertilizer value (1.7 times the N versus lagoon storage). Below-floor storage systems may cause a buildup of odors and gases and can be difficult to agitate and pump out. Remote storage avoids odor and gas buildup in animal housing areas and provides options for methane production and solids separation, but entails additional costs for transfer from the housing facilities to storage.

Operational Factors: Pits must have access for pumping equipment, and outside pits must be covered or fenced to prevent accidental entry into the pit. They should be designed to withstand anticipated hydrostatic, earth, and live loads as well as uplifting in high-water-table areas. Before the pit is filled with manure, water is typically added to prevent solids from sticking to the pit floor. Depths range from 3 to 4 inches under slatted floors and 6 to 12 inches if manure is scraped and hauled to the pit. Sand should not be used as a bedding material because it is incompatible with pumping systems. The pits should always be free of nails, lumber, or other foreign material that can damage equipment.

Demonstration Status: Pit holding is most commonly done at swine operations. *Swine '95* (USDA APHIS, 1996a) reports that pit holding accounts for 25.5, 33.7, and 23.2 percent of farrowing, nursery, and grow-finish operations, respectively. Queries of the *Swine 2000* (USDA APHIS. 2002) data provided information on the use of pits by region, operation type, and size. Swine operations in the Midwest Region use pits most often, with 70.7 percent of the large and 67.7 percent of the medium grow-finish and 56.4 percent of the large and 54.9 percent of the medium farrow-to-finish operations using pits. Swine operations in the Mid-Atlantic Region use pits to a lesser degree, with 37.5 percent of the large and 26.3 percent of the medium grow-finish operations and 23.9 percent of the large and 14.4 percent of the medium farrow-to-finish operations using pits.

Below-floor slurry or deep pit storage is reported in *Dairy '96* (USDA APHIS, 1996b) at 7.9 percent of all dairy operations. Based on EPA site visits, about 33 percent of veal operations are believed to utilize pit storage systems. Beef feedlots do not typically utilize pit storage.

Practice: Belowground or Aboveground Storage Tanks

Description: Belowground and aboveground storage tanks are used as an alternative to under-building pit storage and earthen basins. Both aboveground and belowground tanks are commonly constructed of concrete stave, reinforced monolithic concrete, lap or butt joint coated steel, or spiral wound coated steel with concrete floors. Current assembly practices for aboveground storage facilities are primarily circular silo types and round concrete designs, but the structures may also be rectangular. Belowground storage can be located totally or partially below grade. All storage tanks must be engineered to withstand operational constraints including internal and external hydrostatic pressure, flotation and drainage, live loads from equipment, and loads from covers and supports. Belowground tanks should be surrounded by fences or guardrails to prevent people, livestock, or equipment from accidently entering the tank.

When located directly adjacent to the animal housing facility, belowground tanks are easily filled by scraping directly into the tank. In those situations where the storage tank is not adjacent to the animal housing facility, a collection pit or sump is necessary for loading. In these systems a large piston or pneumatic manure pump forces waste through a large-diameter underground pipe. Aboveground tanks at a lower grade than the livestock housing facility can often be gravity-fed through a similar underground pipe. The tank can be loaded from the top or bottom. Bottom loading in aboveground tanks is most appropriate for manure that forms a surface crust, such as cattle manure. The inlet pipe is usually located 1 to 3 feet above the bottom of the tank to prevent blockages from solids. An advantage to bottom loading is that it pushes solids away from the inlet pipe and distributes them more evenly. Top loading is suitable and most common for manures that do not crust (i.e., liquid swine manure); however, top loading in an aboveground system requires that manure be pumped against gravity. Figure 8-6 shows a typical aboveground storage tank.

Application and Performance: Aboveground or belowground tanks are suitable for operations handling slurry (semisolid) or liquid manure. This generally excludes open-lot waste which is inconsistent in composition and has a higher percentage of solids. Furthermore, because of the

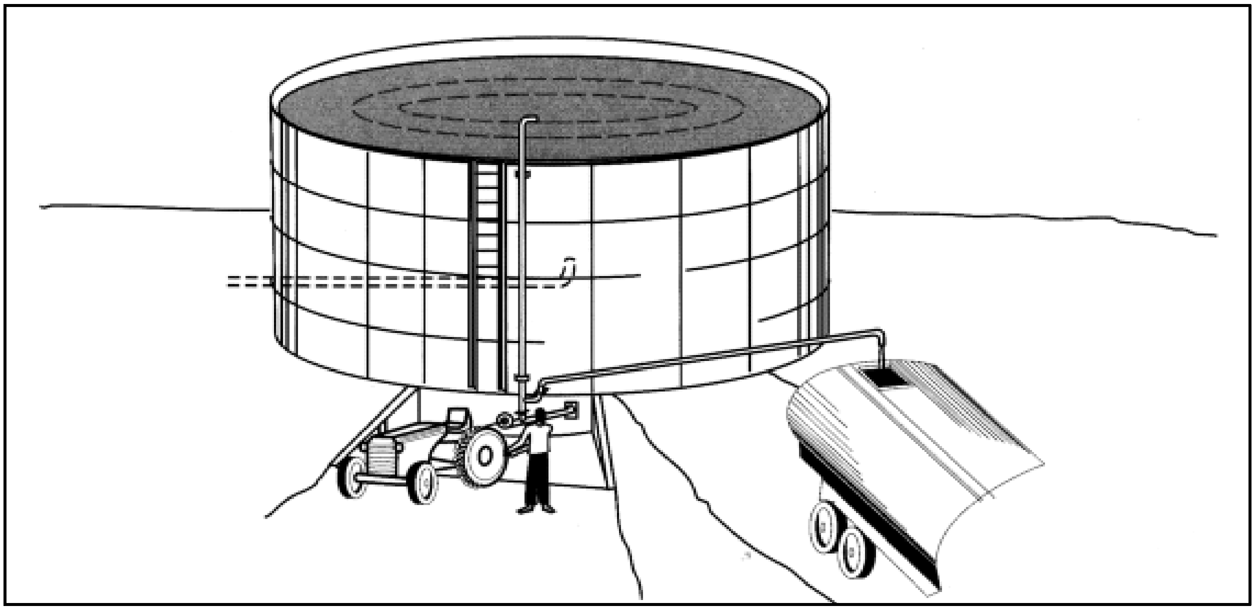

Figure 8-6. Aboveground waste storage tank (USDA NRCS, 1996).

high cost of storage volume, prefabricated storage tanks are generally used to contain only waste, but not runoff, from the livestock facility.

Below and aboveground storage tanks are appropriate and preferred alternatives in situations where the production site has karst terrain, space constraints, or aesthetics issues associated with earthen basins. Storing manure in prefabricated or formed storage tanks is especially advantageous on sites with porous soils or fragmented bedrock. Such locations may be unfit for earthen basins and lagoons because seepage and ground water contamination may occur. Construction of formed storage tanks often includes installation of a liner beneath the concrete to prevent seepage. Aboveground formed storage facilities allow visual monitoring for leaking. Aboveground tanks may exhibit unsightly leaks at seams, bolt holes, or joints, but these are usually quickly sealed with manure. In these storage systems the joint between the foundation and sidewall is the greatest concern. Leaching and ground water contamination can occur if the tank is not sealed properly.

Proper operational practices to maintain adequate storage tank capacity between land applications are critical. The holding volume of a storage tank consists of five fractions: residual volume, manure/waste storage volume (bedding, wasted feed, water added for manure handling), wash water volume, net rainfall and evaporation change, and freeboard capacity.

In general, large amounts of water are not added during the handling of manure that is stored in an above or belowground storage tanks. Installation costs usually dictate that capacity be limited to manure storage requirements. Thus, water conservation is often practiced by facilities that use above or belowground storage tanks. For these facilities, recycling of wastewater is not an option because the manure is generally in slurry form with more than 4 percent solids.

Above and belowground storage tanks are simply storage facilities, and they do not facilitate treatment of the manure. Thus, there is little to no effect on the reduction of nutrients, pathogens, solids, heavy metals, growth hormones, or antibiotics. N in liquid manure is predominately in the inorganic form. This allows for some ammonia volatilization into the atmosphere and a reduction in the total amount of N.

Advantages and Limitations: When these systems are used, manure agitation is necessary before the contents of the storage structure are pumped into a tanker wagon for land application. Agitation ensures uniform consistency of manure and prevents the buildup of solids, thus maintaining the storage capacity of the tank. Agitation results in a more even distribution of nutrients in the manure prior to land application. It can be accomplished with high-horsepower, propeller-type agitators or by recirculating with a high-capacity pump. The length of time the manure needs to be agitated depends on the size of the storage tank, the volume of manure it contains, the percent of solids in the manure, and the type of agitator. Manure with up to 15 percent solids can be agitated and pumped. Because of the potential for agitation and pumping problems, only small amounts of chopped bedding are recommended for use in systems using storage tanks. Some types of agitators have choppers to reduce the particle size of bedding and solids. Dilution with additional water may be necessary to reduce agitation problems. One design variation places the pump in a sump outside the tank, using it for both agitation and pumpouts.

Manure in a storage tank undergoes some anaerobic decomposition, releasing odorous and potentially toxic gases, such as ammonia and hydrogen sulfide. Methane is also produced. Covers can be installed to interrupt the flow of gases up from the liquid surface into the atmosphere. Types of covers range from polyethylene, concrete, or geotextile to biocovers such as chopped straw. Various covers have been shown to reduce odors by up to 90 percent. Furthermore, particular types of covers can be used as methane reservoirs to collect and contain gases from the digestion process for disposal by flaring or converting to electrical power. Moreover, certain covers can prevent rainwater dilution and accumulation of airborne silts and debris. Finally, it is generally accepted that some types of covers control N volatilization into the atmosphere and maintain the N content of the manure.

The installation costs associated with prefabricated storage tanks are high when compared with other liquid manure-handling systems. Glass-lined steel tanks are typically associated with the highest cost. The useful life of the tanks depends on the specific manufacturer and the operator’s maintenance practices. Once they have been installed, above and belowground storage tanks have a low labor requirement, especially when designed as a gravity feed system (Purdue Research Foundation, 1994).

Operational Factors: Specific storage structure designs will vary by state because of climate and regulatory requirements. Pumping manure during freezing conditions can be a problem unless all pipes are installed below the freezing level in the ground. Design considerations in these systems include check valves if bottom loading is used, pumping power with respect to the maximum head, and pipe friction from the pump to the storage.

Demonstration Status: Belowground and aboveground storage tanks are in use nationwide in swine, poultry, and dairy operations. They are appropriate for use in all slurry-based manure-handling systems including those with shallow-pit flush systems, belt or scrape designs, or open-gutter flush systems.

Practice: Solid Poultry Manure Storage in Dedicated Structures

Description: In the broiler and turkey segments of the poultry industry, specially designed pole-type structures are typically used for the temporary storage of solid poultry manure; however, horizontal (bunker) silo-type structures are also used. Manure produced in “high-rise” houses for caged laying hens does not require a separate storage facility if handled as a solid.

A typical pole-type storage structure is 18 to 20 feet high and 40 feet wide. The length depends on the storage capacity desired but is usually a minimum of 40 feet. The structure will have a floor of either compacted soil or concrete, the latter being more desirable but much more expensive. The floor elevation should be at a height above grade that is adequate to prevent any surface runoff from entering the structure. A properly sited structure will be oriented parallel to the direction of the prevailing wind. Equipment access will be through the lee side, which will have no wall. The other three sides of the structure will have walls extending from the floor to a height of 6 to 8 feet. Experience has shown that a higher wall on the windward side of the building excludes precipitation more effectively. Walls may be constructed using pressure-treated lumber or reinforced concrete. Wooden trusses covered with steel sheets are most commonly used for roofing, although plywood roof decking covered with composition shingles is also an option. Manure is usually stacked to a height of 5 to 8 feet. Figure 8-7 shows three types of permanently covered solid manure storage structures.

Horizontal silo-type storage structures are also used for the temporary storage of solid poultry manure. These storage structures can be constructed using either post-and-plank or reinforced concrete walls on three sides. Equipment access will be through the lee side which will have no wall. Concrete walls can be poured in place or made with prefabricated sections that are manufactured for horizontal silo construction. Wall height can be from as low as 3 to 4 feet to as high as 8 to 10 feet if prefabricated concrete sections are used. Usually, there is a concrete floor.

Again, floor elevation should be sufficiently above grade to prevent surface runoff from entering the structure. With this type of storage structure, 6-mil or heavier plastic is typically used to cover the stored manure, but tarpaulins have also been used. As with horizontal silos, old tires

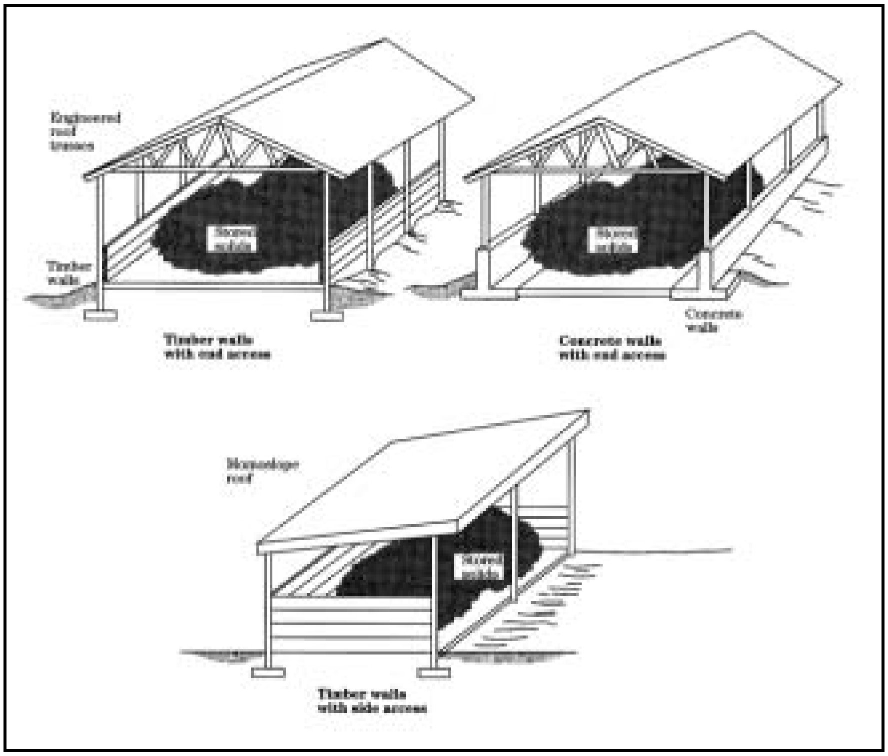

Figure 8-7. Roofed solid manure storage (USDA NRCS, 1996).

are commonly used to secure the cover, although ropes or cables can also be used. Manure is usually stacked to a height of 5 to 8 feet.

In the broiler industry, total cleanouts of production facilities occur only after a minimum of 1 year of production. A total cleanout frequency of 2 to 3 years is not uncommon. Total cleanouts may be more frequent for brood chambers, but the frequency depends on the cost and availability of bedding material, the incidence of disease, the concentration of gaseous ammonia within the production facility, and the policy of the integrator. Caked manure, also known as crust, is removed after every flock, typically a period of 49 days for 4- to 5-pound broilers. Usually, storage structures are designed only for the storage of this caked manure because most broiler growers view the cost of a structure large enough to store manure and litter from a total cleanout as prohibitively high. Because caked manure production varies with the type of bedding material, type of watering system, and climatic conditions, storage requirements may vary from farm to farm. Also, cake production increases with bedding age. Local experience is usually relied upon to estimate storage requirements.

In the turkey industry, total cleanouts of brooder facilities occur after every flock to control disease, but grow-out facilities are typically totally cleaned out only once a year. Again, most turkey growers consider the cost of storage of the manure and bedding from a total cleanout of grow-out facilities to be prohibitively high. Therefore, structures are typically sized only for the storage of manure and bedding from brooder houses.

Application and Performance: The temporary storage of solid poultry manure in a dedicated structure is applicable to all poultry operations at which birds are maintained on a bedding material. Thus, this practice is applicable to all broiler and turkey operations and the small fraction of egg-producing operations that do not house birds in cages. The combination of manure and bedding generated in these operations has a moisture content of less than 50 percent, usually 25 to 35 percent, and is handled as a solid. This practice is not necessary for caged laying hens in high-rise housing because the production facility has a manure storage capacity of 1 or more years.

When sized and managed correctly, storage of solid poultry manure in a dedicated structure will allow for the most efficient use of plant nutrients in the manure for crop production. This eliminates the potential for contamination of surface and ground waters resulting from open stacking of manure or spreading during the fall, winter, early spring, and after crop establishment, when there is no potential for crop uptake. When the stored manure is effectively protected from precipitation, odor and fly problems are minimal. Odor can be a problem, however, when the manure is removed from the storage structure and spread on cropland.

The storage of caked broiler litter and turkey brooder house manure and bedding reduces the potential impact of these materials on surface and ground water quality; however, a substantial fraction of the manure and bedding produced by these segments of the poultry industry is not stored because the associated cost is viewed as prohibitive. The material resulting from the total cleanout of broiler houses and turkey grow-out facilities is often stored temporarily in open piles or spread at inappropriate times of the year. Thus, storage, as currently practiced, is probably not as effective in reducing water quality impacts as is presently thought.

Advantages and Limitations: A correctly sized and managed storage structure allows application to cropland when nutrients will be most efficiently used, thus minimizing negative impacts on surface and ground waters as noted above. If application to cropland is not a disposal alternative, storage can facilitate off-site disposal other than application to cropland.

The principal disadvantage of storing solid poultry manure in a dedicated structure is the cost of the structure and additional material handling costs. Currently, sources of government assistance are available (e.g., cost-share funds available from local soil and water conservation districts) to partially offset construction costs and encourage the adoption of this practice.

Operational Factors: Spontaneous combustion in stored poultry manure has been a problem and has led to the recommendation that stacking height be limited to 5 to 8 feet to avoid excessive compaction. Fires in solid poultry manure storage structures, like silo fires, are extremely difficult to extinguish and often lead to the total loss of the structure.

Demonstration Status: Permanent covered structures for storage of solid manure are used extensively in the broiler and turkey segments of the poultry industry. In a 1996 survey of broiler growers on the Delmarva Peninsula, 232 of 562 respondents indicated that they used a permanent storage structure (Michele et al., 1996).

Practice: Concrete Pads

Description: Concrete pads are used as semi-impermeable surfaces upon which to place waste. The waste pile is often open to the environment, but it can be covered with a roof or plastic sheeting to minimize exposure to the elements. Pads are often sloped to a central location to allow for drainage of rainwater and runoff.

The design for concrete pads varies according to the type of waste it receives (wet or dry) Waste that includes settled solids from a settling basin or solids separator has a high moisture content. In this case, the concrete pad typically has at least two bucking walls to contain the waste and to facilitate the loading and unloading of waste onto the pile. The design height of the waste pile does not exceed about 4 feet, because of the semiliquid state of the waste. For operations with drier waste, the concrete pad typically does not have bucking walls, and the maximum height of the manure pile is 15 feet, because the manure is drier and can be stacked more easily.

Figure 8-8 illustrates the design of a concrete pad (MWPS,1993; USDA NRCS, 1996). Concrete pads are between 4 and 6 inches thick and are made of reinforced concrete to support the weight of a loading truck. The concrete pad is underlain by 4 inches of sand and 6 inches of gravel. The pad is sloped to divert storm water runoff from the pile to the on-site waste management facility, such as a lagoon or a pond. Bucking walls, made of reinforced concrete, are 8 inches thick and 3 to 4 feet tall.

Application and Performance: Concrete pads are used at AFOs to provide a surface on which to store solid and semisolid wastes that would otherwise be stockpiled directly on the feedlot surface. Manure scraped from dry lots and housing facilities and solids separated from the waste stream in a solids separator can be stored on a concrete pad.

The pads provide a centralized location for the operation to accumulate excess manure for later use on site (e.g., bedding, land application) or transportation off site. A centralized location for stockpiling the waste also allows the operation to better control storm water runoff (and associated pollutants). Rainwater that comes into contact with the waste is collected on the

concrete pad and is directed to a pond or lagoon and is thereby prevented from being released on the feedlot. The pad also provides an impermeable base that minimizes or prohibits seepage of rainfall, leaching pollutants or nutrients from the waste and infiltrating into the soil beneath it. The waste is not treated once it is on the concrete pad; the pad serves as a pollution prevention measure. However, with regular handling of the waste, the N loads in the waste will be released into the atmosphere through volatilization, and both N and P may be contained in runoff from the pile after storm events. Pathogen content, metals, growth hormones, and antibiotics loads are not expected to decrease significantly on the concrete pad unless the pile ages considerably.

Advantages and Limitations: An advantage to using a concrete pad for storage is to control runoff and prevent waste from contaminating the surrounding environment. When rainwater or

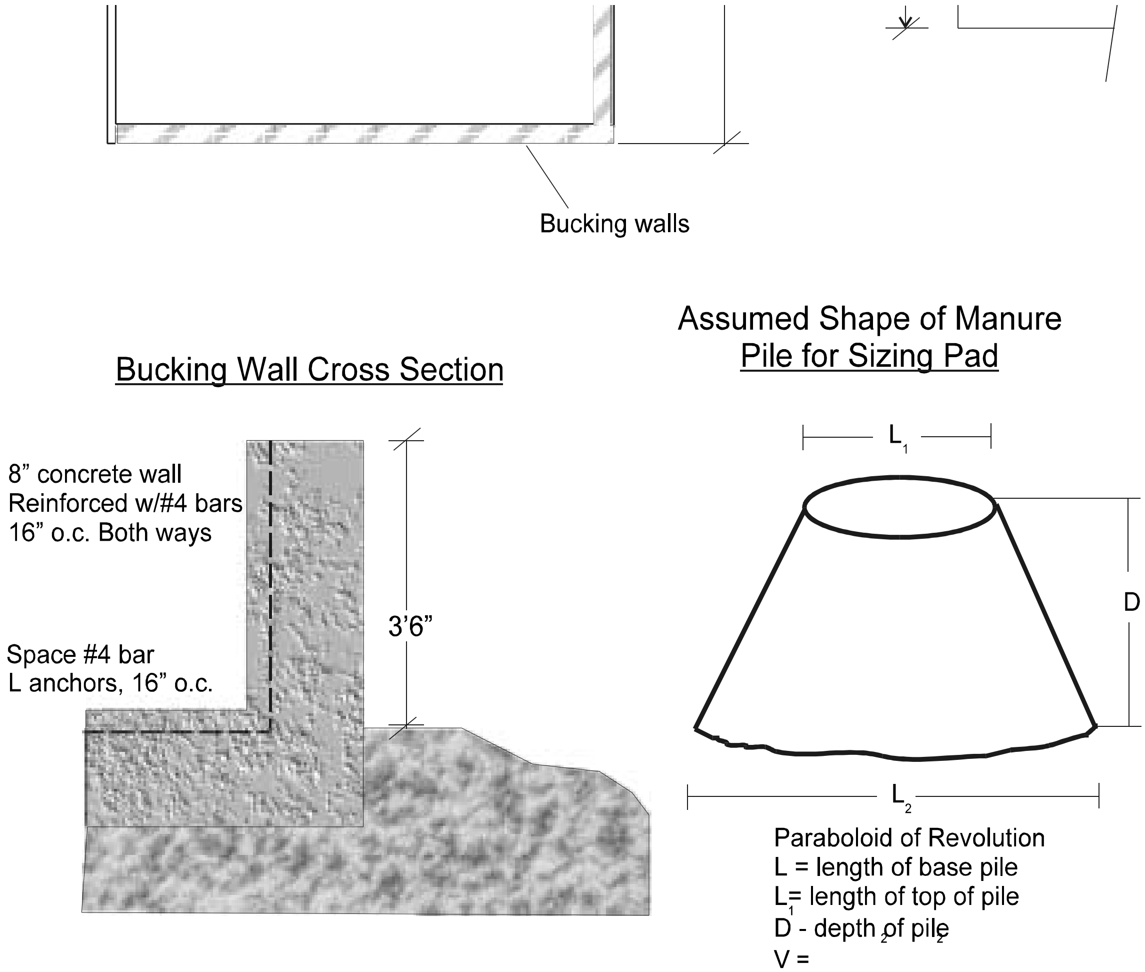

Figure 8-8 Concrete pad design.

precipitation comes into contact with the pile, the water may percolate through the pile, carrying pollutants along the way. The water may exit the pile as runoff and carry pollutants to surface waters or seep into the ground. The concrete pad and bucking walls minimize this potential seepage into and runoff onto the ground around the pile.

Depending on the duration of storage required, however, these pads can take up a very large area. An operation may not have sufficient area to install a concrete pad large enough to store waste in one place. It can also be expensive to construct a concrete pad large enough to accommodate the amount of waste that would accumulate over an appropriate storage time.

Waste stored on a concrete pad will still need to be further managed, either by land application or by transportation off site. There may be some odors from the pile on a concrete pad, but no more than would be expected from any manure stored in a pile.

Operational Factors: Operations that frequently transport their waste will require less storage volume than operations that have less frequent hauling schedules. Operations requiring less storage capacity will require a smaller pad area, resulting in lower capital costs.

Demonstration Status: Concrete pads are used relatively infrequently in the livestock industry. They are more commonly used in dairies than in poultry, beef or swine operations, because dairy waste is semisolid and bucking walls are needed to contain the waste effectively, given the higher moisture content. Waste from swine operations is generally too wet to stack on a pad, and beef and poultry waste is usually piled directly on the feedlot.

8.2.3 Waste Treatment Technologies and Practices

8.2.3.1 Treatment of Animal Wastes and Wastewater

Some treatment systems store waste as well as change the chemical or physical characteristics of the waste. Anaerobic lagoons are the most common form of treatment for AFOs. Other technologies use oxidation to break down organic matter. These include aerated lagoons and oxidation ditches for liquids and composting for solids.

Practice: Anaerobic Digesters for Methane Production and Recovery

Description: An anaerobic digester is a vessel that is sized both to receive a daily volume of organic waste and to grow and maintain a steady-state population of methane bacteria to degrade that waste. Methane bacteria are slow growing, environmentally sensitive bacteria that grow without oxygen and require a pH greater than 6.5 to convert organic acids into biogas over time. Anaerobic digestion can be simplified and grouped into two steps. The first step is easy to recognize because the decomposition products are volatile organic acids that have disagreeable odors. During the second step, methane bacteria consume the products of the first step and produce biogas—a mixture of carbon dioxide and methane—a usable fuel by product. A properly operating digester will produce a gas with minimal odor because methane bacteria from the second step reach a population large enough to rapidly consume the products of the first step. There are three basic temperature regimes for anaerobic digestion: psychrophilic, mesophilic, and thermophilic. Psychrophilic, or low-temperature, digestion is the natural decomposition path for manures at temperatures found in lagoons. These temperatures vary from about 38 to 85 °F (3 to 29 °C). The hydraulic retention time (HRT) required for stable operation varies from 90 days at low temperatures to 30 days at higher temperatures. Methane production will vary seasonally with the variation in lagoon temperature.

Maintaining a constant elevated temperature enhances methane production. Mesophilic digestion cultivates bacteria that have peak activity between 90 and 105 °F (32 to 40 °C). Mesophilic digesters operate at a retention period of 12 to 20 days. Thermophilic digesters promote bacteria that grow at between 135 to 155 °F (57 to 68 °C); these digesters operate with a retention time of 6 to 12 days.

Although there are many types of anaerobic digesters, only covered lagoons operating at ambient temperatures, complete-mix digesters, and plug-flow digesters can be considered commercially available, because they are the only ones that have been implemented successfully at 10 or more sites.

A cover can be floated on the surface of a properly sized anaerobic lagoon to recover methane. Ideally, the cover is floated on the primary lagoon of a two-cell lagoon system, with the primary lagoon maintained as a constant volume treatment lagoon and the second cell used to provide storage of treated effluent until the effluent can be properly applied to land. The lagoons are not heated, and the lagoon temperature and biogas production vary with ambient temperatures. Coarse solids, such as hay and silage fibers in cow manure, must be separated in a pretreatment step and kept from the lagoon. If dairy solids are not separated, they will float to the top and form a crust. The crust will thicken, reducing biogas production and eventually filling the lagoon.

A complete-mix digester is a biological treatment unit that anaerobically decomposes animal manures using controlled temperature, constant volume, and mixing. These digesters can accommodate the widest variety of wastes. Complete-mix digesters are usually aboveground, heated, insulated, round tanks; however, the complete-mix design has also been adapted to function in a heated, mixed, covered earthen basin. Mixing can be accomplished with gas recirculation, mechanical propellers, or liquid circulation. In Europe, some mixed digesters are operated at thermophilic temperatures; however, most of these are regional digesters that are built and operated by digester professionals. A complete-mix digester can be designed to maximize biogas production as an energy source or to optimize VS reduction with less regard for surplus energy. Either process is part of a manure management system, and supplemental effluent storage is required.

Plug-flow digesters are heated, unmixed, rectangular tanks. New waste is pumped into one end of the digester, thereby displacing an equal portion of older material horizontally through the digester and pushing the oldest material out through the opposite end. Lusk (1998) refers to a slurry-loop digester as a separate digester category, but this system, which is built in the shape of a horseshoe, functions by displacement in the same manner as a plug-flow digester.

Biogas formed in a digester bubbles to the surface and may be collected by a fixed rigid top, a flexible inflatable top, or a floating cover, depending on the type of digester. Biogas from a stable digester is saturated and contains 60 to 80 percent methane, with the balance as carbon dioxide and trace amounts of hydrogen sulfide (1,800 to 5,000 ppm H_2S). A collection system directs the virtually odorless biogas to gas-handling components. Biogas may be filtered for mercaptan and moisture removal before being pumped or compressed to operating pressure and then metered to equipment for use. Biogas that is pressurized and metered can be used as fuel for heating, adsorption cooling, electrical generation, or cogeneration.

Application and Performance: Properly designed anaerobic lagoons are used to produce biogas from dilute wastes with less than 2 percent total solids (98 percent moisture) including flushed dairy manure, dairy parlor wash water, and flushed hog manure. Complete-mix digesters can be used to decompose animal manures with 3 to 10 percent TS. Plug-flow digesters are used to digest thick wastes (11 to 13 percent TS) from ruminant animals including dairy and beef animals. The plug-flow system operates best with scrape-collected, fresh dairy manure that contains low levels of dirt, gravel, stones, or straw.

Anaerobic digestion is one of the few manure treatment options that reduce the environmental impact of manure and produce a commodity—energy—that can be used or sold continuously. Digesters are used to stabilize manures to produce methane, while at the same time reducing odors.

Approximately 35 percent of the VS from dairy manure and 60 percent of the VS from swine or beef manure can be converted to biogas and removed from the manure liquid.

Table 8-11 summarizes the performance expected from anaerobic digesters. Anaerobic digesters will reduce BOD and TSS by 80 to 90 percent, and virtually eliminate odor. The digester will have minimal effect on the nutrient content of the digested manure passing through plug-flow or complete-mix digesters. Half or more of the organic N (Org-N) is converted into ammonia (NH_3-N). In lagoons, the concentrations of nutrients are reduced through settling, volatilization, and precipitation. With a cover in place, ammonia volatilization losses are eliminated, leaving only settling and precipitation as pathways for N loss. A small amount of the P and K will settle as sludge in most digesters.

Table 8-11. Anaerobic Unit Process Performance.

	Percentage Reduction						
Digester type	**HRT (days)**	**COD**	**TS**	**VS**	**TN**	**P**	**K**
Complete-mix	12–20	35–70	25–50	40–70	0	0	0
Plug-flow	18–22	35–70	20–45	25–40	0	0	0
Covered first cell of two-cell lagoon	30–90	70–90	75–95	80–90	25–35	50–80	30–50

Source: Moser and Martin, 1999.

The reductions of P, K, or other nonvolatile elements reported in the literature for covered lagoons are not really reductions at all. The material settles and accumulates in the lagoon, awaiting later management. Vanderholm (1975) reported P losses of up to 58 percent. Bortone et al. (1992) suggest that P accumulation in anaerobic lagoons may be due to high pH driving phosphate precipitation as $Ca(PO_4)_2$ and $Mg(PO_4)_2$. This is consistent with and supported by P mass losses documented in most lagoon studies. Water-soluble cations, such as Na, K, and ammonium N, tended to be distributed evenly throughout the lagoon. Humenik et al. (1972) found that 92 to 93 percent of the copper(Cu) and zinc(Zn) in anaerobic swine lagoon influent was removed and assumed to be settled and accumulated in sludge.

Pathogen reduction is greater than 99 percent in mesophilic and thermophilic digesters with a 20-day HRT. Digesters are also very effective in reducing weed seeds.

Advantages and Limitations: Some advantages of anaerobic digestion include the opportunity to reduce energy bills, produce a stabilized manure, recover a salable digested solid by-product, reduce odor and fly breeding, and produce a protein-rich feed from the digested slurry.

The energy from biogas can be used on site as a fuel or sold to a local utility company. On-site uses include the heating of the digester itself, fuel for boilers or electric generators, hot water production, and refrigeration. The equipment listed in Table 8-12 can use biogas in lieu of low-pressure natural gas or propane.

Table 8-12. Biogas Use Options.

Electrical generator	electricity for use or sale, heat recovery optional
Refrigeration compressors	cooling, heat recovery optional
Irrigation pumps	pumping, heat recovery optional
Hot water boiler	for space heat, hot water for process and cleanup
Hot air furnace	for space heat
Direct fire room heater	for space heat
Adsorption chiller	for cold water production, heat recovery optional

Dairy waste digesters partially decompose fibrous solids to a uniform particle size that is easily separated with a mechanical separator. The recovered solids are valuable for reuse as cow bedding or can be sold as a bagged or wholesale soil product.

Limitations include the costs associated with building and operating the digester. Furthermore, nutrient concentrations in the semisolid anaerobic digestion product are not reduced substantially unless they are then stored for several months. Therefore, the amount of land needed for land application of manure is greater than that needed for uncovered lagoons and other treatment practices.

Operational Factors: The successful operation of a properly designed digester is dependent upon two variables: feed rate and temperature. All other operational issues are related to ancillary equipment maintenance. Once a properly designed digester is operating, it will usually continue to function unless management oversight is lacking. Reactor capacity is maintained through periodic removal of settled solids and grit.

A sudden drop in biogas production or pH (from accumulation of organic acids) will indicate digester upset. Factors that decrease the efficiency of microbial processes and might result in digester upset include a change in temperature or feed rations, a change in manure loading rates, or the addition of large quantities of bacterial toxins. A normal ratio of alkalinity to volatile acids during a stable or steady-state anaerobic decomposition is 10:1. The known operating range is 4:1 to 20:1. (Metcalf and Eddy, 1979). An increase in volatile acids resulting in an alkalinity to volatile acid ratio of 5:1 indicates the onset of failure of methane-producing anaerobic digestion (unbalanced decomposition) (Chynoweth, 1998).

The level of hydrogen sulfide in the produced biogas can be controlled through either scrubbing or managed operation of equipment. Scrubbing is necessary for some gas uses but is generally expensive and maintenance intensive.

Demonstration Status: Anaerobic lagoons with covers were used at 1.8 percent of grow-finish operations in 1995 (USDA APHIS, 1999). Approximately 30 pig lagoons have been covered in the United States for odor control or methane recovery (RCM, 1999). The oldest continuously operating covered swine waste lagoon is at Roy Sharp's Royal Farms in Tulare, California. This system, which was installed in 1981, has been producing electricity with the recovered methane since 1983. Not all covered lagoon projects have beneficial uses for recovered methane; some farms either flare or release the gas.

The oldest complete-mix pig manure digester in the United States was built in 1972. Approximately 10 units are in operation today, 6 of which were built within the last 4 years. Many digesters are not operational, typically because the farm is no longer in the pig business. At least 16 operating plug-flow and slurry-loop digesters are currently operating in the United States (Lusk, 1998; RCM, 2000).

Practice: Single-Cell Lagoon With Biogas Generation

Description: In this practice, a cover is floated on the surface of a properly sized anaerobic lagoon to recover biogas (70 percent methane and 30 percent carbon dioxide). Anaerobic lagoons can produce biogas from any type of animal manure. The most successful arrangement consists of two lagoons connected in series to separate biological treatment for biogas production and storage for land application. A variable-volume, one-cell lagoon designed for both treatment and storage can be covered for biogas recovery; however, a single-cell lagoon cover presents design challenges due to the varying level of the lagoon surface.

In the early 1960s, the floating cover industry expanded beyond covering water reservoirs into floating covers for industrial wastewater lagoons. Covering industrial organic wastewater lagoons began as an odor control technique. Within the discovery that economic quantities of biogas could be recovered, cover systems were refined to collect and direct biogas back to the factory producing the organic waste. Lagoon design was optimized to provide both good BOD/COD reduction and a supply of usable biogas. Today, hundreds of industrial anaerobic lagoons have floating covers that optimize anaerobic digestion, control odor, and recover biogas. The industries that use such covers include pork processors and rendering plants in the United States. Lessons learned in the development of floating covers are incorporated into today's designs for animal waste facilities.

Psychrophilic, or low-temperature, digestion is the natural decomposition path for manures at the temperatures found in lagoons. These temperatures vary from about 38 to 85 °F (3 to 29 °C). The retention time required for stable operation varies from 120 days at low temperatures to 30 days at the higher temperatures. Methane production varies seasonally with lagoon temperature. More methane is produced from warmer lagoons than from colder lagoons.

The USDA NRCS (1999) developed Practice Standard 360, Covered Anaerobic Lagoon, to guide floating cover design, installation, and operation. Many types of materials have been used to cover agricultural lagoons. Floating covers are not limited in dimension. A floating cover allows for some gas storage. Cover materials must have a bulk density near that of water and must be UV-resistant, hydrophobic, tear- and puncture-resistant, and nontoxic to aquatic aerobes and anaerobes.

Several types of material are used to construct floating covers, including high-density polyethylene, XR-5, polypropylene, and hypalon. Material is selected based on material properties (such as UV resistance), price, availability, installation, and service. Installation teams with appropriate equipment travel and install covers.

Biogas formed in a digester bubbles to the surface and is collected and directed by the cover to a gas use. Biogas from a stable covered lagoon is virtually odorless and saturated. It contains 70 to 85 percent methane; the balance is carbon dioxide and trace amounts of hydrogen sulfide (1,000 to 3,000 ppm H_2S). Biogas can be harmful if inhaled directly, corrosive to equipment, and potentially explosive in a confined space when mixed with air. When properly managed, the off-gas is as safe as any other fuel (e.g., propane) used on the farm. Safety concerns are more completely addressed in the *Handbook of Biogas Utilization* (Ross et al., 1996).

Biogas may be filtered for mercaptan and moisture removal. Biogas is usually pumped or compressed to operating pressure and then metered to the gas use equipment. Biogas can be used as fuel for heating, electrical generation, or cogeneration. Alternatively, it can simply be flared for odor control.

Application and Performance: Covered lagoons are used to recover biogas and control. Covers can be installed to completely cover the lagoon and capture clean rainwater. The uncontaminated rainwater can be safely pumped off, reducing the volume of lagoon liquid to be managed later.

Off-gases collected by an impermeable cover on an anaerobic manure facility are neither explosive nor combustible until mixed with air in proper proportions to support combustion. No reports of any explosions of biogas systems at animal production facilities were found.

Table 8-13 summarizes the performance expected from covered lagoons. Anaerobic digestion in a covered lagoon will reduce BOD and TSS by 80 to 90 percent. Odor is virtually eliminated.

Table 8-13. Anaerobic Unit Process Performance

		Percentage Reduction					
Digester type	HRT Days	COD	TS	VS	TN	P	K
Covered lagoon	30–90	70–90	75–95	80–90	25–35	50–80	30–50

Source: Moser et al., 1999.

The concentrations of nutrients are reduced through settling and precipitation in lagoons. Ammonia volatilization losses are virtually eliminated with a cover in place, leaving only settling and precipitation as pathways for N loss.

During anaerobic digestion, microbial activity converts half or more of the Org-N to NH_3-N. Cheng et al., (1999) found that 30 percent of the total TKN (which includes ammonia and organic N) entering the covered first cell of a two-cell lagoon was retained in that cell, probably as Org-N in slowly degradable organics in the sludge. A similar loss due to settling could be expected in a covered single-cell lagoon. A covered single-cell lagoon will not lose NH_3-N to the atmosphere; however NH_3-N will be volatilized from the uncovered second cell of a two-cell lagoon. Cheng et al., (1999) also reported that approximately 50 percent of the influent TKN was subsequently lost from the uncovered second cell of the system.

Reported reductions of P, K, or other nonvolatile elements through a covered lagoon are not really reductions at all. The material settles and accumulates in the lagoon awaiting later management. This is consistent with and supported by P mass losses documented in most lagoon studies. Humenik et al. (1972) found that 92 to 93 percent of the copper and zinc in anaerobic swine lagoon influent was removed and assumed to be settled and accumulated in sludge.

Cheng (1999) found pathogen reduction through a North Carolina covered lagoon to be 2 to 3 orders of magnitude. Martin (1999) determined that relationships between temperature and the time required for a one $\log_{10}$ reduction in densities of pathogens were consistently exponential in form. Although there is substantial variation between organisms regarding the time required for a one $\log_{10}$ reduction in density at ambient temperatures, this work suggests that variation in die-off rates among species decreases markedly as temperature increases. For example, the predicted time required for a one $\log_{10}$ reduction in fecal streptococcus density decreases from 63.7 days at 15 °C to 0.2 day at 50 °C. For *S. aureus*, the decrease is from 10.6 days at 15 °C to 0.1 day at 50 °C. Thus, for both storage and treatment at ambient temperature, an extended period of time is predicted for any significant reduction. A single-cell covered lagoon has a longer residence time than the covered first cell of a two-cell lagoon and should therefore have a greater reduction of pathogens. However, during pumpout of a single-cell lagoon, fresh influent can be short-circuited to the pumpout, carrying pathogens with it, whereas the covered first cell of a two-cell lagoon produces a consistent pathogen reduction without short-circuiting because the first cell's pathogen-destroying retention time is not affected when the second cell is pumped down.

Advantages and Limitations: The advantages of covered anaerobic lagoons are the reduction of lagoon odor, exclusion of rainfall from the lagoon, recovery of usable energy, reduction of ammonia volatilization, and reduction of methane emissions. There are also significant labor savings involved in handling manure as a liquid and being able to apply lagoon waters to the land through irrigation. Solids are broken down through microbial activity, and organic matter is stabilized when anaerobic digestion is complete, reducing the potential for production of noxious by products. A bank-anchored cover prevents the growth of weeds where the cover is placed. Finally, treated lagoon water can be recycled for flush water in confinement houses, resulting in cost savings in areas where water is scarce.

Limitations of covered anaerobic lagoons include the cost of installing a cover, which in 1999 varied from \$0.37 to \$1.65 per square foot (Martin, 1999), and the occasional need for cover maintenance such as rip repair, and rainfall pump off. The lagoons themselves can be large, depending on the size of the hog operation, and can require a significant amount of cover material. Spills and leaks to surface and ground water can occur if the lagoon capacity is exceeded, or if structural damage occurs to berms, seals, or liners. The treatment capacity of most lagoons is diminished by sludge accumulation, and sludge has to be removed and managed.

Operational Factors: Lagoons should be located on soils of low permeability or soils that seal through biological action or sedimentation, and proper liners should be used to avoid contamination of ground water. Proper sizing and management are necessary to effectively operate a covered anaerobic lagoon and maintain biogas production. The minimum covered lagoon capacity should include treatment volume, sludge storage, freeboard, and, if necessary, storage for seasonal rainfall and a 25-year, 24-hour rainfall event.

Temperature is a key factor in planning the treatment capacity of a covered lagoon. The lagoons are not heated, and the lagoon temperature and biogas production vary with ambient temperatures. Warm climates require smaller lagoons and have less variation in seasonal gas production. Colder temperatures will reduce winter methane production. To compensate for reduced temperatures, loading rates are decreased and hydraulic retention time is increased. A larger lagoon requires a larger, more costly cover than a smaller lagoon in a warmer climate.

The floating cover must be designed and operated in such a way as to keep it from billowing in windy conditions. Coarse solids, such as hay and silage fibers in cow manure, must be separated in a pretreatment step and kept from the lagoon. If dairy solids are not separated, they float and form a crust. The crust will thicken, reducing biogas production and eventually filling the lagoon.

Proper lagoon inspection and maintenance are necessary to ensure that lagoon liners and covers are not harmed by agitating and pumping, berms and embankments are stable, and the required freeboard and rainfall storage are provided. Sampling and analysis of the lagoon water are suggested to determine its nutrient content and appropriate land application rates.

Anaerobic lagoons accumulate sludge over time, diminishing treatment capacity. Lagoons must be cleaned out once every 5 to 15 years, and the sludge can be applied to land other than the spray fields receiving the lagoon liquid. Because crop P requirements are less than those for N, it takes more land to apply the sludge from lagoon cleanout than to apply liquid wastewater.

Demonstration Status: Floating-cover technology is well developed and readily available. Covering lagoons for odor control has been demonstrated in all sectors of the animal production industry. The installation of floating covers specifically for methane recovery is a less common, but well-known practice. There are at least 10 covered lagoon systems with biogas collection and combustion in the pig and dairy industries (Lusk, 1998; RCM, 2000).

Practice: Aerobic Treatment of Liquids

Description: Conventional aerobic digestion is a process used frequently at small municipal and industrial wastewater treatment plants for biosolids stabilization. It is a suspended growth process operating at ambient temperature in the stationary or endogenous respiration phase of the microbial growth curve. In the stationary phase, the exogenous supply of energy is inadequate to support any net microbial growth. Endogenous respiration occurs when the exogenous supply of energy is also inadequate to satisfy cell maintenance requirements, and a net decrease in microbial mass occurs. Operating parameters include a relatively long period of aeration, ranging from several days to more than 30 days depending on the degree of stabilization desired. Given the relatively long period of aeration, activated sludge recycling is not necessary and hydraulic detention and solids retention times are equal in continuous-flow systems. This is a major difference between aerobic digestion and the various variants of the activated sludge process including extended aeration (see “Secondary Biological Treatment” below). When aerobic digestion is used for biosolids stabilization, either the fill-and-draw or the continuous mode of operation can be used. With the fill-and-draw mode of operation, an option is to periodically cease aeration temporarily to allow settling and then decant the clarified liquid before resuming aeration. This approach also allows the reactor to be used as a biosolids thickener.

With conventional aerobic digestion, substantial reductions in TS, and VS, BOD, COD, and Org-N can be realized. Total N reduction can also be substantial, with either ammonia stripping or nitrification-denitrification serving as the primary mechanism, depending on the dissolved oxygen concentration of the mixed liquor. Actual process performance depends on a number of variables including solids retention time, temperature, and adequacy of oxygen transfer and mixing.

An aeration basin is typically used for the aerobic digestion of municipal and industrial wastewater biosolids. In contrast, several reactor types, including oxidation ditches and mechanically aerated lagoons, as well as aeration basins, have been used for the aerobic digestion of animal manures. Under commercial conditions, the oxidation ditch has been the most commonly used because it can be located in the animal housing unit under cages for laying hens or under slatted floors for swine. This eliminates the need for transport of manure to the treatment system.

It should be noted that since the oxidation ditch was originally developed to employ the activated sludge process used in municipal wastewater treatment, the term “activated sludge” has been used incorrectly on occasion to describe the aerobic digestion of swine, poultry, and other animal wastes. Aerobic digestion, not the activated sludge process, is employed in oxidation ditches, mechanically aerated lagoons, and aeration basins. Table 8-14 presents technologies that use aerobic digestion or the activated sludge process.

Table 8-14. Operational Characteristics of Aerobic Digestion and Activated Sludge Processes.

Process Modification	Flow Model	Aeration System	BOD Removal Efficiency (percent)	Remarks
Conventional	Plug flow	Diffused-air, mechanical aerators	85–95	Use for low-strength domestic wastes. Process is susceptible to shock loads.
Complete mix	Continuous-flow stirred-tank reactor	Diffused-air, mechanical aerators	85–95	Use for general application. Process is resistant to shock loads, but is susceptible to filamentous growths.
Step feed	Plug flow	Diffused air	85–95	Use for general application for a wide range of wastes.
Modified aeration	Plug flow	Diffused air	60–75	Use for intermediate degree of treatment where cell tissue in the effluent is not objectionable.
Contact stabilization	Plug flow	Diffused-air, mechanical aerators	80–90	Use for expansion of existing systems and package plants.
Extended aeration	Plug flow	Diffused-air, mechanical aerators	75–95	Use for small communities, package plants, and where nitrified element is required. Process is flexible.
High-rate aeration	Continuous-flow stirred-tank reactor	Mechanical aerators	75–90	Use for general applications with turbine aerators to transfer oxygen and control floc size.
Kraus process	Plug flow	Diffused air	85–95	Use for low-N, high-strength wastes.
High-purity oxygen	Continuous-flow stirred-tank reactors in series	Mechanical aerators (sparger turbines)	85–95	Use for general application with high-strength waste and where on-site space is limited. Process is resistant to slug loads.
Oxidation ditch	Plug flow	Mechanical aerators (horizontal axis type)	75–95	Use for small communities or where large area of land is available. Process is flexible.
Sequencing batch reactor	Intermittent-flow stirred-tank reactor	Diffused air	85–95	Use for small communities where land is limited. Process is flexible and can remove N and P.
Deep-shaft reactor	Plug flow	Diffused air	85–95	Use for general application with high-strength wastes. Process is resistant to slug loads.
Single-stage nitrification	Continuous-flow stirred-tank reactors or plug flow	Mechanical aerators, diffused-air	85–95	Use for general application for N control where inhibitory industrial wastes are not present.
Separate stage nitrification	Continuous-flow stirred-tank reactors or plug flow	Mechanical aerators, diffused-air	85-95	Use for upgrading existing systems, where N standards are stringent, or where inhibitory industrial wastes are present and can be removed in earlier stages.

Source: Metcalf and Eddy Inc., 1991.

Application and Performance: Conventional aerobic digestion is an option for all swine and poultry operations where manure is handled as a liquid or slurry, and it can be used with flushing systems using either mixed liquor or clarified effluent as flush water. With proper process design and operation, a 75 to 85 percent reduction in 5-day biochemical oxygen demand (BOD_5) appears achievable, with a concurrent 45 to 55 percent reduction in COD, and a 20 to 40 percent reduction in TS (Martin, 1999). In addition, a 70 to 80 percent reduction of the N in both poultry and swine wastes via nitrification-denitrification also appears possible. Total P is not reduced, but the soluble fraction may increase. As with aerobic digestion of biosolids, some reduction in pathogen densities may also occur depending on process temperature.

Advantages and Limitations: In addition to the potential for substantial reductions in oxygen-demanding organics and N, one of the principal advantages of aerobic digestion of poultry and swine manures is the potential for a high degree of odor control. Another advantage is the elimination of fly and other vermin problems.

Limitations include high energy requirements for aeration and mixing (e.g., pumps, blowers, or mixers for mechanical aeration). In addition, aerobic lagoons without mechanical aeration are generally shallow, requiring a very large land area to meet oxygen demands. The absence of a reduction in the volume of waste requiring ultimate disposal is another limitation. In certain situations, waste volume will be increased significantly. For example, use of an undercage oxidation ditch versus a high-rise type system to manage the waste from laying hens will substantially increase the waste volume requiring ultimate disposal. Also, management, maintenance, and repair requirements for aerobic digestion systems can be significant. For example, liquids and solids must be separated in a pretreatment step when aerated lagoons are used.

Operational Factors: Establishing and maintaining an adequate microbial population in aerobic digestion reactors is critical to ensure optimal process performance. Failure to do so will lead to excessive foam production, which has suffocated animals on slatted floors above in-building oxidation ditches. Failure to remove slowly biodegradable solids on a regular basis to maintain a mixed liquor total solids concentration of about 1 percent in fill-and-draw systems will lead to a substantial reduction in oxygen transfer efficiency and mixing. This results in reduced treatment efficiency and the potential for generation of noxious odors and release of poisonous gases, particularly hydrogen sulfide. Because ambient temperature determines process temperature, seasonal variation in process performance occurs.

Demonstration Status: Aerobic digestion has not been adapted to any significant degree by the poultry, dairy, or swine industries, although a number of research and demonstration scale studies were conducted in the late 1960s and early 1970s. Problems related to process and facilities design, together with the significant increase in electricity costs in the early to mid-1970s, led to a loss of interest in this animal waste treatment alternative. It is possible that no aerobic digestion systems for animal wastes are currently in operation in the poultry and swine industries.

Lagoons are the most popular method of treatment for livestock manure. Aerobic lagoons are commonly used for secondary treatment and storage of anaerobic lagoon wastes. Despite the advantages, however, aerobic lagoons are considered uneconomical for livestock manure treatment.

Practice: Autoheated Aerobic Digestion

Description: Autoheated aerobic digestion uses heat released during the microbial oxidation of organic matter to raise process temperature above ambient levels. This is accomplished by minimizing both sensible and evaporative heat losses through the use of insulated reactors and aeration systems with high-efficiency oxygen transfer. Mesophilic temperatures, 86 °F (30 °C) or higher, can typically be maintained even in cold climates, and thermophilic temperatures as high as 131 to 149 °F (55 to 65 °C) can be attained. Both ammonia stripping and nitrification-denitrification can be mechanisms of N loss at mesophilic temperatures; nitrification-denitrification is typically the principal mechanism if the aeration rate is adequate to support nitrification. Because both *Nitrosomas* and *Nitrobacter*, the bacteria that convert ammonium ions into nitrate, are mesophiles, N loss at thermophilic temperatures is limited to ammonia stripping. Typically, autoheated digestion reactors are operated as draw-and-fill reactors to minimize influent short-circuiting, especially when maximizing pathogen reduction is a treatment objective.

Application and Performance: Autoheated aerobic digestion is appropriate for all livestock and poultry operations where manure is handled as a slurry that has a minimum TS concentration of at least 1 to 2 percent, wet basis. At lower influent total solids concentrations, such as those characteristic of flushing systems, achieving process temperatures significantly above ambient levels is problematic because of an insufficient biological heat production potential relative to sensible and evaporative heat losses. As influent TS concentration increases, the potential for achieving thermophilic temperatures also increases. Influent TS concentrations of between 3 and 5 percent are necessary to attain thermophilic temperatures.

With proper process design and operation, the previously discussed reductions in BOD_5, COD, TS, and total N that can be realized with conventional aerobic digestion also can be realized with autoheated aerobic digestion (Martin, 1999). Autoheated aerobic digestion can also provide significant reductions in pathogen densities in a relatively short 1- to 2-day treatment period. Reductions realized are a function of process temperature. At a process temperature of 122 °F (50 °C) or greater, a minimum of at least a one $\log_{10}$ reduction in the density of most pathogens is highly probable, with two to three $\log_{10}$ reductions likely (Martin, 1999).

Advantages and Limitations: With respect to waste stabilization and odor control, the potential benefits of conventional and autoheated aerobic digestion are comparable. The principal advantages of autoheated aerobic digestion relative to conventional aerobic digestion from a process performance perspective are (1) higher reaction rates that translate into shorter detention times to attain a given degree of stabilization, and (2) more rapid reduction in densities of pathogens. The time required to achieve comparable reductions in BOD_5, COD, TS, and total N is much shorter in autoheated than in conventional aerobic digestion. With autoheated aerobic digestion, these reductions occur within 1 to 3 days at thermophilic temperatures, whereas 15 days or more are required with conventional aerobic digestion at ambient temperatures. This translates directly into smaller reactor volume requirements.

The ability to provide rapid and substantial (at least a one $\log_{10}$) reductions in pathogen densities is one of the more attractive characteristics of autoheated aerobic digestion. This ability has been demonstrated in several studies of autoheated aerobic digestion of biosolids from municipal wastewater treatment, including a study by Martin (1999).

The high energy requirements for aeration and mixing are limitations of autoheated aerobic digestion. In addition, waste volume is not reduced through the treatment process. However, the requirement of a less dilute influent waste stream, as compared with conventional aerobic digestion, for example, to provide the necessary biological heat production potential translates into reduced ultimate disposal requirements.

Operational Factors: A foam layer covering the mixed liquor in autoheated aerobic digestion reactors is a common characteristic and serves to reduce both sensible and evaporative heat losses. It is necessary to control the depth of this foam layer to ensure that an overflow of foam from the reactor does not occur. Typically, mechanical foam cutters are used. Although autoheated aerobic digestion is less sensitive to fluctuations in ambient temperature than are other treatment processes, such as conventional aerobic digestion, some reduction in treatment efficiency can occur, especially during extended periods of extremely cold weather.

Demonstration Status: The feasibility of using autoheated aerobic digestion to stabilize swine manure has been demonstrated in several studies (Martin, 1999). Feasibility also has been demonstrated in several studies with cattle manure, including studies by Terwilliger and Crauer (1975) and Cummings and Jewell (1977). There does not appear to have been any comparable demonstration of feasibility with poultry wastes. Given the similarities in the composition of swine and poultry wastes, it is highly probable that autoheated aerobic digestion of poultry wastes is also technically feasible. Although no data are available, it is probable that this waste treatment technology is not currently being used in any segment of animal agriculture, primarily because of the associated energy cost.

Practice: Secondary Biological Treatment

Description: The activated sludge process is a widely used technology for treating wastewater that has high organic content. The process was first used in the early 1900s and has since gained popularity for treatment of municipal and industrial wastewater. Many versions of this process are in use today, but the fundamental principles are similar. Basically, the activated sludge process treats organic wastes by maintaining an activated mass of microorganisms that aerobically decomposes and stabilizes the waste.

Primary clarification or solids settling is the first step in the activated sludge process. Next, the organic waste is introduced into a reactor. Maintained in suspension in the reactor is a biological culture that converts the waste through oxidation and synthesis. The aerobic environment in the reactor is achieved using diffused or mechanical aeration, which also maintains a completely mixed state. After a specified period, the HRT, the mixture in the reactor is passed to a settling tank. A portion of the solids from the settling tank is recycled to the reactor to maintain a balance of microorganisms. Periodically, solids from the settling tank are "wasted" or discharged to maintain a specific concentration of microorganisms in the system. The solids are discharged according to a calculated solids retention time (SRT), which is based on the influent characteristics and the desired effluent quality. The overflow from the settling tank is discharged from the system.

Application and Performance: The activated sludge process is very flexible and can be used to treat almost any type of biological waste. It can be adapted to provide high levels of treatment under a wide range of operating conditions. Properly designed, installed, and operated activated sludge systems can reduce the potential pollution impact of feedlot waste because this technology has been shown to reduce carbon-, N-, and P-rich compounds.

In the activated sludge process, N is treated biologically through nitrification-denitrification. The supply of air facilitates nitrification, which is the oxidation of ammonia to nitrite and then nitrate. Denitrification takes place in an anoxic environment, in which the bacteria reduce the nitrate to nitrogen gas (N_2), which is released into the atmosphere. The activated sludge process can nitrify and denitrify in single- and double-stage systems.

P is removed biologically when an anaerobic zone is followed by an aerobic zone, causing the microorganisms to absorb P at an above-normal rate. The activated sludge technology most effective for removing P is the sequencing batch reactor (SBR) (see "Sequencing Batch Reactors," below).

N and P can both be removed in the same system. The SBR is also most effective for targeting removal of both N and P because of its ability to alternate aerobic and anaerobic conditions to control precisely the level of treatment.

Advantages and Limitations: An advantage of the activated sludge process is that it removes pollutants, particularly nutrients, from the liquid portion of the waste. Nutrient removal can allow more feedlot wastewater to be applied to land without overloading it with N and P. Furthermore, concentrating the nutrients in a sludge portion can potentially reduce transportation volumes and costs of shipping excess waste.

A disadvantage of an activated sludge system compared to an anaerobic lagoon is the relatively high capital and operating costs and the complexity of the control system. In addition, because pollutants will remain in the sludge, stabilization and pathogen reduction are necessary before disposing of it.

Because the activated sludge process does not reduce pathogens sufficiently, another way to reduce pathogens in both the liquid and solid portions of a waste may be appropriate prior to discharge or land application. The liquid effluent from an activated sludge system can be disinfected by using chlorination, ultraviolet radiation, or ozonation, which are the final steps in many municipal treatment systems.

Operational Factors: Many parameters can affect the performance of an activated sludge system. Organic loading must be monitored carefully to ensure that the microorganisms can be sustained in proper concentrations to produce a desired effluent quality. The principal factors in the control of the activated sludge process are:

- Maintaining dissolved oxygen levels in the aeration tank (reactor).
- Regulating the amount of recycled activated sludge from the settling tank to the reactor.
- Controlling the waste-activated sludge concentration in the reactor.

Ambient temperature can also affect treatment efficiency of an activated sludge system. Temperature influences the metabolic activities of the microbial population, gas-transfer rates, and settling characteristics of biological solids. In cold climates, a larger reactor volume may be necessary to achieve treatment goals because nitrification rates decrease significantly at lower temperatures.

Demonstration Status: Although activated sludge technologies have not been demonstrated on a full-scale basis in the animal feedlot industry, the process may treat such waste effectively. Studies have been performed on dairy and swine waste to determine the level of treatment achievable in an SBR (see "Sequencing Batch Reactors," below). The SBR is simpler, more flexible, and perhaps more cost-effective than other activated sludge options for use in the feedlots industry.

Practice: Sequencing Batch Reactors

Description: An SBR is an activated sludge treatment system in which the processes are carried out sequentially in the same tank (reactor). The SBR system may consist of one reactor, or more than one reactor operated in parallel. The activated sludge process treats organic wastes by maintaining an aerobic bacterial culture, which decomposes and stabilizes the waste. An SBR has five basic phases of operation, which are described below.

<u>Fill Phase</u>: During the fill phase, influent enters the reactor and mechanical mixing begins. The mixing action resuspends the settled biomass from the bottom of the reactor, creating a completely mixed condition and an anoxic environment. As wastewater continues entering the reactor, oxygen may also be delivered, converting the environment from anoxic to aerobic. Depending on the desired effluent quality, the oxygen supply can be operated in an "on/off" cycle, thus alternating the aerobic and anoxic conditions and accomplishing nitrification and denitrification.

React Phase: During the react phase, wastewater no longer enters the reactor. Influent to the system is instead either stored for later treatment in a single-reactor system or diverted to another reactor to begin treatment in a system with multiple reactors. Mechanical mixing continues throughout this phase. The oxygen supply may be operated in a cyclical manner, as described in the fill phase, to accomplish additional denitrification if necessary. Activated sludge systems, such as SBRs, depend upon developing and sustaining a mixed culture of bacteria and other microbes (i.e., the biomass) to accomplish the treatment objectives.

Settle Phase: During the settle phase, the oxygen supply system and mechanical mixer do not operate. This phase provides a quiescent environment in the reactor and allows gravity solids separation to occur, much like in a conventional clarifier.

Draw Phase: Following the treatment of a batch, it is necessary to remove from the reactor the same volume of water that was added during the fill phase. After a sufficient settling phase, the liquid near the top of the reactor is decanted to a predetermined level and discharged or recycled.

Idle Phase: The idle phase is a time period between batches during which the system does not operate. The duration of this unnecessary phase depends on the hydraulic aspects of the reactor. However, as a result of biological degradation and accumulation of inert materials from the wastewater, solids must be discharged from the reactor periodically to maintain a desirable level of mixed liquor suspended solids. This “sludge wasting” is done during the idle phase, or immediately following the draw phase.

Application and Performance: SBR technology could be applied to reduce the potential pollution impact of liquid manure waste from dairies because this technology has been shown to reduce carbon-, N-, and P-rich compounds. Removing these pollutants from the liquid portion of the waste could allow for greater hydraulic application to lands without exceeding crop nutrient needs. Concentrating the nutrients in the sludge portion could potentially reduce transportation volumes and cost of shipping excess waste. Although a proven technology for treatment of nutrients in municipal wastewater, available data does not exist showing SBRs to be effective in pathogen reduction.

Given the processes it employs, SBR treatment may allow treated dairy wastewater to be either applied to land or discharged to a stream if a sufficient level of treatment can be achieved. Further, the sludge from the wasting procedure could be applied to land, composted, or sent off site for disposal. Aqua-Aerobic Systems of Rockford, Illinois, (Aqua-Aerobics, 2000) estimates a sludge production rate of approximately 1.3 pounds of waste-activated sludge per pound of BOD_5 entering the system. The use of SBRs to treat dairy waste has been studied in the laboratory at both Cornell University and the University of California at Davis. Both studies have shown SBR technology to be effective in reducing pollutants in the liquid portion of dairy waste, although neither report included specific information on sludge characteristics or P removals (Johnson and Montemagno, 1999; Zhang et al., 1999).

In the Cornell study, diluted dairy manure was treated in bench-scale reactors (Johnson and Montemagno, 1999). Experiments were conducted to determine the operating strategy best suited for the diluted dairy manure. The study resulted in removals of 98 percent of ammonia (NH_3), 95 percent of COD, 40 percent of nitrate/nitrite (NO_3/NO_2), and 91 percent of inorganic N.

The University of California at Davis studied how SBR performance was affected by HRT, SRT, organic loading, and influent characteristics of dairy wastewater (Zhang et al., 1999). The highest removal efficiencies from the liquid portion of the waste were for an influent COD concentration of 20,000 mg/L (a COD concentration of 10,000 mg/L was also studied) and an HRT of 3 days (HRTs of 1 to 3 days were studied). With these parameters, laboratory personnel observed removal efficiencies of 85.1 percent for NH_3 and 86.7 percent for COD.

In addition, studies on SBR treatment of swine waste in Canada and of veal waste in Europe have demonstrated high removal rates of COD, N, and P (Reeves, 1999).

Advantages and Limitations: Technology currently used at dairies includes solids settling basins followed by treatment and storage of waste in an anaerobic lagoon. Lagoon effluent and solids are applied to cropland in accordance with their nutrient content, and excess water or solids are then transported off site. The SBR could replace treatment in an anaerobic lagoon, but there would still be a need for solids separation in advance of SBR treatment, as well as a pond or tank to equalize the wastewater flow. In fact, Aqua-Aerobics (2000) has indicated that solids removal and dilution of the raw slurry would be necessary to treatment in the SBR. Following the SBR, it is possible that some type of effluent storage would be required for periods when direct irrigation is not possible or necessary.

Use of an SBR is expected to be advantageous at dairies that apply a portion of their waste to land. The reduced level of nutrients in the liquid portion would allow for application of a greater volume of liquid waste, thereby reducing the volume of waste that must be transported off site and possibly eliminating liquid waste transport. An SBR is also beneficial in the handling of the solids portion of the waste because no periodic dredging is required as is the case with anaerobic lagoons. Disadvantages of an SBR system are the relatively high capital and operating costs, as well as the need to manage the nutrients that remain in the sludge.

Because the activated sludge process is not a generally accepted method of pathogen reduction, another means of reducing pathogens in both the liquid and solid portions of the dairy waste may be appropriate. Disinfection of the liquid effluent from the SBR could be accomplished through use of chlorination, ultraviolet radiation, or ozonation which are used as the final step in many municipal treatment systems. Composting has also been demonstrated as a means of reducing pathogens in organic solid waste and could be implemented for use with the SBR sludge.

Operational Factors: The five phases of SBR operation may be used in a variety of combinations in order to optimize treatment to address specific influent characteristics and effluent goals. N in the activated sludge process is treated biologically through the nitrification-denitrification process. The nitrification-denitrification process in the SBR is controlled through the timing and cyclical pattern of aeration during the react phase. The supply of air causes nitrification, which is the oxidation of ammonia to nitrite and then nitrate. To accomplish denitrification, the air supply is shut off, creating an anoxic environment in which the bacteria ultimately reduce the nitrate to N_2, which is released to the atmosphere. The cycle can be repeated to achieve additional levels of denitrification. Some portion of the N in the influent to the SBR may also volatilize prior to treatment, and a portion may also be taken up by microorganisms that are present in the waste-activated sludge (Zhang et al., 1999).

P is removed when an anaerobic zone (or phase) is followed by an aerobic zone, causing the microorganisms to take up P at an above-normal rate. The waste-activated sludge containing the microorganisms is periodically "wasted" as described above. As such, the bulk of the P will be concentrated ultimately in the sludge portion with a minimal amount remaining in the liquid effluent.

N and P can both be removed in the same system. This dual removal is accomplished by beginning the fill phase without aeration, which creates an anoxic condition allowing for some denitrification as well as release of P from the cell mass to the liquid medium. There follows a period of aerated mixing, which will continue into the react phase, allowing for nitrification and uptake of P. The settle phase, in which no aeration occurs, is extended sufficiently to allow for additional denitrification. Again, these phases can be repeated or executed for varying durations in order to accomplish specific treatment goals.

Demonstration Status: Although the SBR technology has not been demonstrated on a full-scale basis in the dairy industry, SBRs are currently being evaluated for use at dairies because they generate a high volume of wastewater. Dairy wastewater treated in the SBR includes a combination of parlor and barn flush/hose water and runoff.

Cornell University is currently studying two pilot-scale SBR systems to further investigate the treatability of dairy waste (Johnson and Montemagno, 1999). No results from the pilot-scale study are yet available, although preliminary results for nutrient removal have been favorable and a full-scale system is being planned.

Practice: Solids Buildup in the Covered First Cell of a Two-Cell Lagoon

Description: This section addresses sludge accumulation, removal, and management in the first cell of a two-cell lagoon. The first cell may or may not be covered for methane recovery. Some sludge will be carried from the first cell to the second cell; however, the quantity is not significant compared with potential accumulations in the first cell. No quantitative information was found regarding the differences in the rate of accumulation of sludge in the first cell versus accumulation in a single-cell lagoon. The removal and management of sludge from the first cell of a two-cell lagoon will be the same as described for sludge cleaning from a single cell lagoon.

For the purpose of this section, sludge is material settled on the bottom of a lagoon receiving waste from any animal; it has a TS content greater than 10 percent, generally has a high angle of repose when dewatered, and will not readily flow to a pump. Sludge includes organic material not decomposed by lagoon bacteria, and inorganic material such as sand and precipitates. Sludge accumulation can eventually fill a lagoon.

Accumulated sludge is removed to restore lagoon treatment and storage capacities. Two general methods of sludge removal, slurry and solid, are described below. When managed as a slurry, sludge is resuspended with agitation and pumped to tankers or irrigation guns for land application. Slurry management is desirable when the sludge mixture can be pumped to an irrigation gun or hauled a short distance. Sludge removed from covered lagoons is removed as a slurry.

Sludge managed as a solid is excavated from the lagoon or pumped from the bottom as slurry to a drying area. Solid sludge is cheaper to haul than slurry because water, which increases the weight and volume, is not added. Solid sludge can be spread with conventional manure spreaders or dumped on fields and spread out and disced into the soil. In drier areas of the country, a lagoon may be withdrawn from service as a parallel lagoon is restored to service. The lagoon liquids are pumped off to field application and the sludge is allowed to dry. After 4 to 12 months, excavators, backhoes or bulldozers scrape, push, pull, or lift the material into trucks or wagons for hauling and spreading. Some lagoons are designed to be desludged by dragline bucket excavators while still in operation. Draglines work along the banks of these long, narrow lagoons, excavating sludge and either dropping it into trucks for hauling or depositing it on the lagoon embankment to dry for later hauling.

Application and Performance: Lagoon cleanout is applicable to all two-cell lagoons, regardless of location. Reported reductions of P, K, and other nonvolatile elements through a lagoon are not really reductions at all because these materials settle. N is considered volatile in the ammonia form, but some Org-N associated with heavier and nondegradable organics also settles into the lagoon sludge and stays, resulting in a high-Org-N fraction of total TKN in settled solids. The settled materials accumulate in the lagoon awaiting later disposal. Compared with lagoon liquids, lagoon sludges have higher concentrations of all pollutants that are not completely soluble. All reported data suggest that the sludge is more stable than raw manure based on its reduced VS/TS. VS are a portion of the TS that can be biologically destroyed, and as they are destroyed, the VS/TS ratio declines.

As anaerobic digestion of manure changes the solution chemistry in a lagoon, materials such as NH_3 and P form precipitates with Ca and Mg. Fulhage and Hoehne (1999) and Bicudo et al. (1999) both report concentrations of Ca, Mg, P, and K in lagoon sludge at 10 to 30 times that found in raw manure. Fulhage and Hoehne also reported that Cu and Zn settle and concentrate to 40 to 100 times the concentration found in lagoon liquid.

Martin (1999), in a review and analysis of factors affecting pathogen destruction, found that time and temperature controlled the die-off rate of pathogens. Sludge that has been in a lagoon for 10 years is expected to have very low concentrations of pathogens, and those would be associated with the most recent 90 to 180 days of settling.

Advantages and Limitations: The advantage of lagoon cleanout is that removal of sludge restores the volume of a first-cell lagoon that is necessary for design treatment capacity. One of the limitations is that sludge disposal is ignored in most NMPs. Sludge is a concentrated, nutrient-rich material. The nutrients in the sludge, if applied to the same cropland historically receiving lagoon liquids, could easily exceed the planned application rate of nutrients. P and other relatively insoluble nutrients are more concentrated than N in sludge and become the basis of planning proper use of the sludge.

Ideally, sludge will be managed as a high-value fertilizer in the year it is applied. As the sludge has a higher nutrient and, hence, cash value than liquid manure, hauling to remote farms and fields to replace commercial fertilizer application is possible and desirable. Proper management of applied sludge will result in successful crops and minimal loss of nutrients to surface or ground waters.

The cover is a limiting factor in covered lagoon cleanout. At least a portion of the cover is removed to allow equipment access. Removing a complete cover is usually not practical. Lacking complete access, covered lagoon cleanouts will not remove all of the sludge present. Therefore, more frequent cleanouts would be expected. Most covered lagoons have been developed with cleanout intervals of 10 to 15 years.

Operational Factors: The USDA allows for sludge accumulation by incorporating a sludge accumulation volume (SAV) in its lagoon design calculations. Table 8-15 shows USDA's ratios of sludge accumulated per pound of TS added to the lagoon. The higher the rate of sludge accumulation assumed in a design, the larger the lagoon volume required. There are no published data to compare sludge accumulation in the first cell of a two-cell lagoon versus accumulation in a single-cell lagoon. Anecdotal observations suggest that a first cell does not accumulate sludge faster than a single-cell lagoon as long as the first cell is sized to contain all of the treatment volume and SAV. In theory, a constant volume first cell should accumulate less sludge over time than a single-cell lagoon because the constant volume lagoon has a consistently higher microbial concentration than a single-cell lagoon. The higher concentration should result in the ability to consume new manure organic solids before they can settle to become sludge. Also in theory, a covered first cell would accumulate less sludge due to higher biological activity because a covered lagoon is a few degrees warmer than an uncovered lagoon.

Table 8-15. Lagoon Sludge Accumulation Ratios.

Animal Type	Sludge Accumulation Ratio
Layers	0.0295 ft^3/lb TS
Pullets	0.0455 ft^3/lb TS
Swine	0.0485 ft^3/lb TS
Dairy cattle	0.0729 ft^3/lb TS

Source: USDA NRCS 1996.

Information from various studies suggests that the USDA values may overestimate actual sludge accumulation rates. Table 8-16 shows a range of long-term sludge accumulation rates reported by various researchers. Field studies by both Fulhage and Hoehne (1999) and Bicudo et al. (1999) show lower accumulation rates than developed by Barth and Kroes (1985) and USDA NRCS (1996).

Table 8-16. Lagoon Sludge Accumulation Rates Estimated for Pig Manure.

Source	Sludge Accumulation Rate
Fulhage (1990)	0.002 m^3/kg LAW*
Bicudo (1999)	0.003 m^3/kg LAW*
Barth (1985)	0.008 m^3/kg LAW*
USDA (1992)**	0.012 m^3/kg LAW*

* LAW = live animal weight ** as calculated by Bicudo et al. (1999).

It is important to note that the accumulation rate of sludge is influenced by lagoon design, influent characteristics, site factors, and management factors. Lagoon design factors such as lagoon volume, surface fetch, and lagoon depth increase or decrease potential lagoon mixing. More lagoon mixing encourages greater solids destruction by increasing the opportunity for bacteria to encounter and degrade solids. Influent factors, including animal type and feed, determine the biodegradability of manure solids. Highly degradable manure solids are more completely destroyed, thus accumulating as sludge to a lesser degree. Site temperature and incident rainfall impact the biological performance of the lagoon. High temperature increases biological activity and solids destruction. High rainfall can fill the lagoon and reduce retention time, thus slowing biological destruction of solids. Management factors also affect sludge accumulation. Increasing animal population, adding materials such as straw or sand used for animal bedding, or adding process water will reduce the ability of a lagoon to destroy solids and, therefore, increase the rate of sludge accumulation. Properly managed solids separators can reduce the quantity of solids reaching the lagoon, hence reducing sludge accumulation.

Demonstration Status: First-cell cleanouts are common and have occurred since two-cell lagoons have been used. In many areas of the country, there are companies that specialize in lagoon cleaning.

Practice: Solids Buildup in an Uncovered Lagoon

Description: For the purpose of this section, sludge is material settled on the bottom of a lagoon receiving waste from any animal; it has a TS content greater than 10 percent, generally has a high angle of repose when dewatered, and will not readily flow to a pump. This definition is intended to distinguish sludge from a less concentrated layer of solids above the sludge surface that can be drawn off with conventional pumping. All lagoons accumulate settleable materials in a sludge layer on the bottom of the lagoon. Sludge includes organic material not decomposed by lagoon bacteria and inorganic material such as sand and precipitates. Over time the sludge accumulation decreases the active treatment volume of a lagoon and negatively impacts the lagoon performance. Reduced treatment performance increases the rate of sludge accumulation. Sludge accumulations can eventually fill a lagoon.

Accumulated sludge is removed to restore lagoon treatment and storage capacities. Two general methods of sludge removal, slurry and solid, are described below.

When managed as a slurry, sludge is resuspended with agitation and pumped to tankers or irrigation guns for land application. Slurry management is desirable when the sludge mixture can be pumped to an irrigation gun or hauled a short distance.

Sludge managed as a solid is excavated from the lagoon. Solid sludge is cheaper to haul than slurry because water, which increases the weight and volume, is not added. Solid sludge can be spread with conventional manure spreaders or dumped on fields and spread out and disced into the soil. In drier areas of the country, a lagoon may be withdrawn from service when a parallel lagoon is restored to service. The lagoon liquids are pumped off to field application, and the sludge is allowed to dry. After 4 to 12 months, excavators, backhoes, or bulldozers scrape, push, pull, or lift the material into trucks or wagons for hauling and spreading. Some lagoons are designed to be desludged by dragline bucket excavators while still in operation. Draglines work along the banks of these long, narrow lagoons, excavating sludge and either dropping it into trucks for hauling or depositing it on the lagoon embankment to dry for later hauling.

Application and Performance: Lagoon cleanout is applicable to all operations that have lagoons, regardless of location. Reported reductions of P, K, and other nonvolatile elements through a lagoon are not really reductions at all. The material settles and accumulates in the lagoon, awaiting later disposal. Compared with lagoon liquids, lagoon sludges have higher concentrations of all pollutants that are not completely soluble. All reported data suggest that the sludge is more stable than raw manure based on its reduced VS/TS ratio. VS are a portion of the TS that can be biologically destroyed, and as they are destroyed, the VS/TS ratio declines. Some Org-N associated with heavier and nondegradable organics also settles into the lagoon sludge and stays, resulting in a high-organic N fraction of TKN in settled solids.

As anaerobic digestion of manure changes the solution chemistry in a lagoon, materials such as NH_3 and P form precipitates with Ca and Mg. Both Fulhage and Hoehne (1999) and Bicudo et al. (1999) report concentrations of Ca, Mg, P, and K in lagoon sludge at 10 to 30 times that found in raw manure. Fulhage and Hoehne also reported that Cu and Zn settle and concentrate to 40 to 100 times the concentration found in lagoon liquid.

Martin (1999), in a review and analysis of factors affecting pathogen destruction, found that time and temperature controlled the die-off rate of pathogens. Sludge that has been in a lagoon for 10 years is expected to have very low concentrations of pathogens, and those would be associated with the most recent 90 to 180 days of settling.

Advantages and Limitations: The advantage of lagoon cleanout is that removal of sludge restores the volume of a lagoon that is necessary for design treatment and storage capacities. One of the limitations is that sludge disposal is ignored in most NMPs. Sludge is a concentrated, nutrient-rich material. The nutrients in the sludge, if applied to the same cropland historically receiving lagoon liquids, could easily exceed the planned application rate of nutrients. P and other relatively insoluble nutrients are more concentrated than N in sludge and become the basis of planning proper use and disposal of the sludge.

Ideally, sludge will be managed as a high value fertilizer in the year it is applied. As the sludge has a higher nutrient and, hence, cash value than liquid manure, hauling to remote farms and fields to replace commercial fertilizer application is possible and desirable. Proper management of applied sludge will result in successful crops and minimal loss of nutrients to surface or ground waters.

Operational Factors: The USDA allows for sludge accumulation by incorporating an SAV in its lagoon design calculations. Table 8-15 shows USDA's ratios of sludge accumulated per pound of TS added to the lagoon. The higher the rate of sludge accumulation assumed in a design, the larger the lagoon volume required.

Information from various studies suggests that the USDA values may overestimate actual sludge accumulation rates. Table 8-16 shows a range of long-term sludge accumulation rates reported by various researchers. Field studies by both Fulhage and Hoehne (1999) and Bicudo et al. (1999) show lower accumulation rates than were developed by Barth and Kroes (1985) and USDA NRCS (1996).

It is important to note that the accumulation rate of sludge is influenced by lagoon design, influent characteristics, site factors, and management factors. Lagoon design factors such as lagoon volume, surface fetch, and lagoon depth increase or decrease potential lagoon mixing. More lagoon mixing encourages greater solids destruction by increasing the opportunity for bacteria to encounter and degrade solids. Influent factors, including animal type and feed, determine the biodegradability of manure solids. Highly degradable manure solids are more completely destroyed, thus accumulate as sludge to a lesser degree. Site temperature and incident rainfall impact the biological performance of the lagoon. High temperature increases biological activity and solids destruction. High rainfall can fill the lagoon and reduce retention time, thus slowing biological destruction of solids. Management factors also affect sludge accumulation. Increasing the animal population, the addition of materials such as straw or sand used for animal bedding, or the addition of process water will reduce the ability of a lagoon to destroy solids and increase the rate of sludge accumulation. Properly managed solids separators can reduce the quantity of solids reaching the lagoon, thereby reducing sludge accumulation. Mixing a lagoon before land application will suspend some of the sludge solids, causing them to be pumped out sooner rather than later.

Demonstration Status: Lagoon cleanouts are common and have occurred since lagoons have been used. Companies that specialize in lagoon cleaning are found in many areas of the country.